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TECHNOLOGY · PRACTICE

JANUARY 1949

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Oxygen in Steelmaking

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Water—Lowest Cost Industrial Mineral

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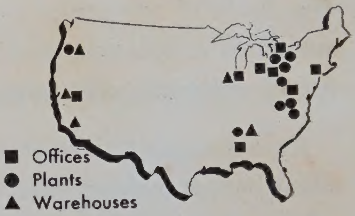

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JANUARY 1949

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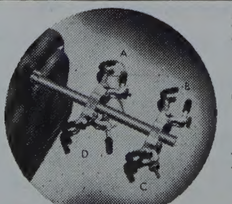

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New Metals Division

As announced in the December issue the bylaws of the Extractive Metallurgy Division were approved by the AIME Board of Directors at their November Meeting. Welcome to the new Division and with its organization the completion of the divisionalization of the Metals Branch. Most of the work of organizing the new Division is being done by the three able and conscientious chairmen of the Reduction and Refining Committee of Lead and Zinc, Aluminum and Magnesium, and Copper—Messrs. Long, Sullivan and Shepard. It is expected that the Reduction of Ferroalloy Ores Committee will become part of the Iron and Steel Division.

Revised bylaws for the Minerals Beneficiation Division were also approved at the November Board Meeting. Considerable discussion took place concerning publication of papers from the two Divisions. Is an operator of a cyanide plant, a copper leaching plant, a roasting plant, or a mercury distillation plant primarily a mineral beneficiator or an extractive metallurgist? The officials of the Minerals Beneficiation Division and of the new Extractive Metallurgy Division each claim these and some other similar fields, in whole or in part. The practical difficulty, so far as the AIME is concerned, is that the technical papers of the former Division are to be published in *Mining Engineering* and of the latter in the JOURNAL OF METALS. Even the individual members immediately concerned are not unanimous in their opinion as to whether they are more closely allied to the Mining or to the Metals Branches, into which the Institute is now broadly divided. A pyrometallurgist, working in a copper smelter, a field of activity not even claimed by the MBD, writes that he works in a mining district, all his friends are mining and millmen, he cannot understand and has no interest in the physical metallurgy papers published in *Metals Technology*, and would like to see all smelting papers published in Mining and Engineering. This seems to be a minority preference however, since a vote taken of all of the members of the three committees forming the new Division favored publishing their papers in the JOURNAL OF METALS by a ratio of 3 to 1. The continuation of the practice of publishing ferrous and nonferrous extractive metallurgy papers in the same magazine, a practice established over ten years ago, seems to be the most logical since the refining of copper in a reverberatory presents some problems in common with open hearth steelmaking as do the operation of ferrous and nonferrous blast furnaces and converters.

Much thought has been given to the problem in the last two or three months and the following solution has been developed by the two Divisions concerned. Authors' wishes as to the medium of publication will be considered as will that of the Divisions' Publications Committees, but ultimate decision will rest with the AIME Technical Publication Committee in order to preserve a reasonable consistency as to the place of publication of any one type of paper. Members in the controversial fields should pick the journal that they think most likely to be of interest to them, and then watch the list of all technical papers published. If they note one in which they are interested published in a journal to which they do not subscribe, they can obtain a copy for 75 cents. Fortunately it does not seem likely that cases of this kind will be too numerous.

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GUEST EDITORIAL

FRANK T. SISCO • DIRECTOR, ALLOYS OF IRON RESEARCH

A STAR IS BORN

For many years there has been a well known and highly respected nebula wandering slowly around the celestial sphere of science and engineering. This loosely agglomerated mass of matter and energy was made up of electrons, protons, neutrons, and positrons of widely varying activity plus a few more-or-less staid and stolid atoms, and it was held together by two factors: first, that all the particles, despite their various energy levels, were active in the same general field—minerals and metals; second, that the well-formed atoms lent stability to the more numerous but highly volatile subatomic individuals.

During the years that this nebula has been in existence it has grown steadily but not spectacularly, notwithstanding the loss of groups of negatively charged particles from time to time; but its speed of rotation and its rate of travel in that particular section of the universe where it belonged were so slow that most observers considered it to be practically static. Recently, however, a phenomenal change occurred; the rate of rotation of this particular nebula suddenly increased; and the result was entirely in accord with the usually accepted hypothesis for the origin of various segments of the universe—a steadily increasing rate of rotation until the nebula was spinning so rapidly that centrifugal force overcame gravitational pull and it broke up into three distinct stars, each with its own path but each related to the others, and all forming a distinct constellation.

This new constellation is the new AIME; the new stars are the branches of mining, metals, and petroleum, and each will shine with a bright light transmitted by three new journals of impeccable perspicacity and wisdom.

It was my privilege to be present when this celestial cataclysm occurred and to have witnessed the labor pains when the new star named Metals was born, and it is an honor to have been requested to write this foreword for the first issue of the medium which will carry the bright light of the new star into the darkest corners of metallurgical art and science.

The goals set by the editors for this new journal are laudible ones, and I feel that there is more than a reasonable chance that they will be reached. In the first place, there will be no hokum behind the headlines; instead, the metallurgical facts of life and their meaning will be clearly and, I trust, adequately presented. Facts in themselves mean little; they create nothing and they solve nothing; they exist and that is all. Whether they acquire any meaning, whether they create or solve anything, depends on what we do with them, and an adequate presentation of the facts in this journal will surely include an objective interpretation.

The second goal is to print articles that are brief and to the point. Brevity is more than the soul of wit; it is the quality that makes speeches, radio programs, and airplane trips, as well as erudite writing, bearable; and this applies particularly to articles in metallurgical journals, many of which indicate that the author was "inebriated with the exuberance of his own verbosity." Brevity is the silken string that ties the pearls of metallurgical knowledge into a single strand, which is a delight to the wearer and to the beholder, and I hope that this will be constantly kept in mind by the editors of this journal and by its contributors.

Advances in the art and science of metallurgy in the United States are frequently far from being consistent or invariable; on the contrary they are often capricious and occasionally contradictory, but it is universally acknowledged that the net result has been the most efficient metal-producing industry in the world today. This has come primarily from the facilities available to the research worker and the production man for presenting to his peers the results of his work, to be criticized on the basis of its intrinsic worth and not because of its "bourgeois" approach or its lack of conformity with some ideology that is popular at the moment with the men in power.

More than two centuries ago, Francis Bacon, one of England's great philosophers and a firm believer in scientific investigation and in clarity of observation, stated "I hold every man a debtor to his profession; from the which as men of course do seek to receive countenance and profit, so ought they of duty to endeavour themselves by way of amends to be a help and ornament thereto."

This is your journal; the editors will do everything possible to make it interesting and important, but they can do much more if you will help. Two thousand years ago a wise man said "if thou hast abundance give abundantly; if thou hast but little be not afraid to give according to that little." Following this advice will profit you as well as your society and your industry.

Steps in production of titanium metal: (Left to right) ilmenite, metal in sponge form, melted and formed into ingots (center), small pieces fabricated from commercially pure metal.

Titanium

By **BRUCE W. GONSER** • RESEARCH SUPERVISOR, BATTELLE MEMORIAL INSTITUTE, COLUMBUS

No longer can titanium be considered a rare metal, or even a little-known metal. The publicity that has been given to it recently has extended all the way from strictly technical papers, through the popular science type of writings, into household magazines with nation-wide circulation. Some of the things said about it are highly dramatic. For instance, a recent popular writer refers to great clouds of titanium dust floating through space, and to whole stars of titanium in the Milky Way. He calls it the "Cinderella of the cosmos," which may be a heaven-sent answer to the prayers of the Navy.

It is true that the astronomers have identified titanium in stellar spectra. It is also true that the metal promises to be useful in a rather big way. But just how useful? Is it the magic metal, the Cinderella element, the big discovery of a new age? How much exaggeration is included in the more popular utterances about it?

There are definite reasons why any metallurgist can become enthusiastic over the future possibilities of titanium, but at least one foot should be kept on the ground when singing its virtues. The most important favorable factors are:

1. There is an abundance of titanium ores in reasonable concentration.
2. The relatively pure metal has excellent metal properties, including good resistance to corrosion.
3. The metal is comparatively light, slightly over half the weight of iron, yet has melting point of 1725C.
4. There are unusually good possibilities of developing exceptional properties by alloying and heat treatment.

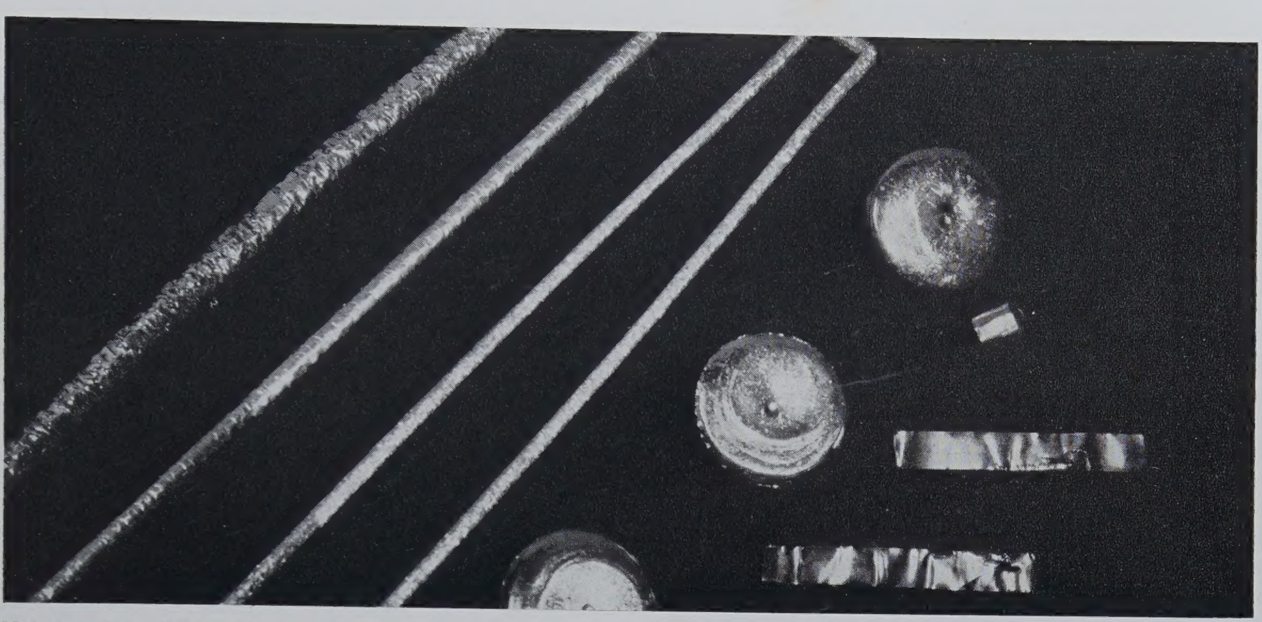
The unfavorable factor which has discouraged use of the metal heretofore is the difficulty of separating the pure metal from its ores. This has been a challenge to the metallurgist which only recently has been met, and still has not been overcome satisfactorily.

occurrence and ores

It is a real pleasure to find that a metal with such good properties is so widespread. Only a few metals exceed it in abundance in the earth's crust—silicon, aluminum, iron, calcium, sodium, potassium, and magnesium. F. W. Clarke in his classic survey of the relative abundance of elements for the U. S. Geological Survey found titanium in 98 per cent of the hundreds of igneous rocks examined. Goldschmidt in a similar and later survey rated titanium as being 20 times as abundant as all the copper, nickel, zinc, tin, lead, and molybdenum combined. Moreover, it is concentrated in sufficiently large deposits to favor economical mining and treatment.

The chief ores of titanium are rutile (a tetragonal form of TiO_2) and compounds of titanium and iron oxides, as ilmenite, largely $FeTiO_3$, and titaniferous magnetite, $FeO \cdot (FeTi)_2O_3$. Ilmenite has been much the most important commercial source of titanium compounds, particularly for producing pigment TiO_2. Rutile has been used largely as a coating for welding rods.

No nation or group of nations has a monopoly on titanium ore production. To cite all the known deposits would sound like the roster of the United Nations and a few more. However, until rather recently, much of the titanium ore used in the United States was imported from such places as Travancore, Brazil, and Senegal, Africa. Now, it comes largely from domestic mines, with particular emphasis on the ilmenite production from the Adirondacks in New York. The ores are readily concentrated,



Hairpins of ductile titanium, as deposited by thermal decomposition of the iodide, after arc melting; also sections of 0.004 in. sheet, rolled without annealing from the rod, as deposited.

the ilmenite usually containing 50-55 per cent TiO_2 and the rutile from 90-98 per cent TiO_2. The demand for more titanium oxide as a pigment, as well as increasing interest in the possibilities of the ductile metal, have encouraged the exploitation of other fields. One of the most promising of these, the Allard Lake ilmenite deposits in Quebec, just south of the Labrador border, is being developed jointly by the Kennecott Copper Corp. and the New Jersey Zinc Co. This development was well described in the November, 1948, issue of *Mining and Metallurgry.*

process metallurgy

Since by far the greatest use for titanium has been as the pure white dioxide pigment, means for producing a high-grade dioxide have been well worked out commercially. This involves chemical extraction of the titanium from the ore, purification, and precipitation of the oxide. The production of pigment dioxide in the United States currently amounts to processing several hundred thousand tons of ilmenite yearly, and the demand is growing. Consequently, there is a healthy dioxide industry which makes available in large quantities and at a reasonable cost (10-20 cents per pound) a very high-grade raw material for production of the metal if more crude sources cannot be used. The wartime demand for titanium tetrachloride for use in making smoke screens aided in developing large-scale economical commercial production of this compound as another high-grade raw material.

Unfortunately for ease of extraction, titanium is one of the most reactive of metals at elevated temperatures. It reacts strongly with nitrogen, carbon, oxygen, and even hydrogen, although the hydrogen can be removed rather completely by a high-temperature vacuum treatment. On attempting to reduce titanium dioxide with carbon, for instance, hard, brittle carbides are formed, or a cyanonitride mixture if nitrogen is present. There may be considerable metal present, but one would never know it from the hardness, brittleness, and general behavior. This means that conventional pyrometallurgy as applied to most common metals is out. Extracting titanium comes more into the province of the chemical engineer and physical chemist than that of the smelterman.

Electrolytic recovery of titanium from aqueous, nonaqueous, and molten salt electrolytes has attracted much research, but scanty hope of success has resulted. This does not mean that some metallic titanium powder can not be produced by these means, but that at the moment the chances for producing high-purity compact deposits are certainly not exciting.

Two general methods are now used for producing metallic titanium—(1) reduction of titanium compounds by another metal, and (2) thermal decomposition of a gaseous titanium halide.

Unlike most metals, it takes very little of some impurities to destroy titanium's good metal properties. Thus, for many years crude titanium has been produced, which, although containing possibly only a few tenths of a per

Bruce W. Gonser

Mr. Gonser has served as metallurgical or chemical engineer with the American Smelting & Refining Co., Superior Zinc Corp., and National Radiator Corp. and has been connected with Battelle Memorial Institute since 1934. He is the author of numerous technical articles and is a member of AIME, American Society for Metals, American Association for the Advancement of Science, Electrochemical Society, Sigma Xi, and of several clubs. He holds numerous patents in the United States and foreign countries. He attended Purdue and Harvard universities. He is well known as an expert on the rare and lesser known metals and therefore highly qualified as the author of this paper.

cent of known impurities, was nonductile and useless as a structural material. Such metal was usually produced in a bomb reaction between sodium and titanium tetrachloride or fluotitanates, but later calcium and calcium hydride were used to reduce the oxide as well as other compounds.

The modern era of titanium production by this general method may be said to have started only a few years ago when the U. S. Bureau of Mines took up the study of developing a commercially practical method of making ductile titanium. A method, first described by Kroll in 1940, was developed through various pilot plant stages until some tons of metal powder could be supplied to investigators, in industry as well as governmental branches, for metallurgical and processing studies. This method consists essentially for reducing gaseous titanium tetrachloride by molten magnesium at about 1000C. in a molybdenum or iron container, and leaching out the magnesium salts from the resultant titanium powder by acid treatment. The clean titanium powder is then pressed into bars and sintered in vacuum at about 1000C. to give compact bars having sufficient ductility to permit not only hot rolling to rod and sheet but some cold working.

This general method has some practical drawbacks, naturally, such as difficulty in removing the solid mass of magnesium salts, residual magnesium and titanium powder from the reaction chamber, in handling finely divided titanium, and the general limitations and expense of converting the powder to a compact solid by powder metallurgy. Research consequently has been done with considerable success, and is continuing, on simplification and improvement. As an indication of the commercial status, duPont is now selling titanium sponge at $5.00 per pound, and has exhibited a 100 pound ingot as well as various wrought shapes made by arc melting. The Dominion Magnesium Co. in Canada, has also announced commercial production of powder for use in making ductile titanium.

iodide process

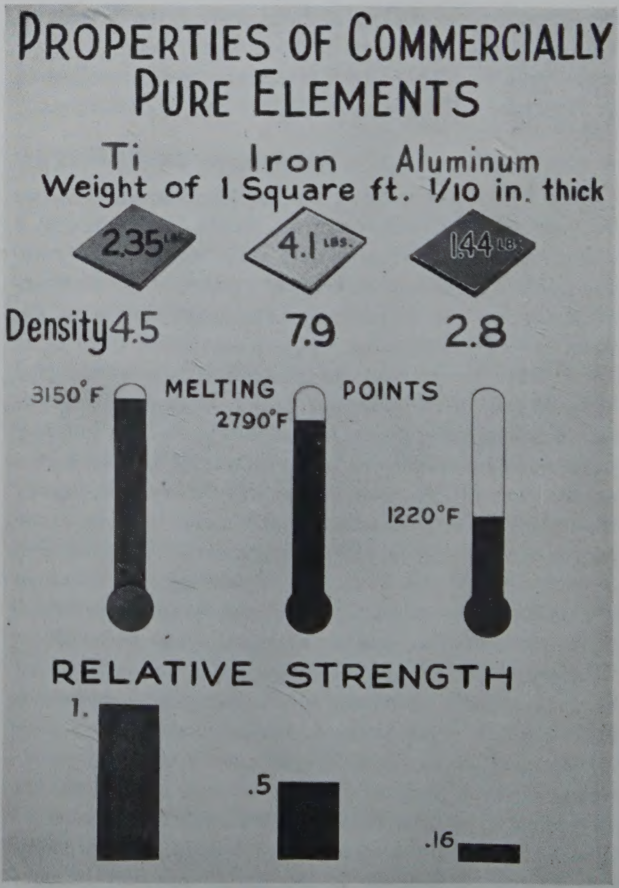
Relatively pure ductile titanium has been produced in the compact form by deBoer, Van Arkel, Fast and others as described in the German literature as far back as 1925. This method has been to refine titanium by reacting the crude metal in an evacuated glass bulb with iodine at a slightly elevated temperature, then decomposing the resultant iodide on a hot tungsten filament. Iodine is thereby regenerated to carry on the cyclical action, and the filament grows in diameter until it reaches the electrical or thermal limits of the equipment. (The tetrabromide has been used in place of the iodide, but similar decomposition of the chloride has not been so successful.)

Recently considerable improvement has been made in this process, and chances are good for much further development. Thus, the tungsten filament has been replaced by a titanium wire so the product is uncontaminated, the purity of the product, as judged by properties, has been improved, metal containers have replaced glass equipment, and the operation has been made simpler and more practical. Solid rods of ⅝-in. diam. have been produced and the diameter and length seem to be limited only by the electrical and mechanical limitations of the equipment used. So far, there has been no announcement of titanium produced by this method for commercial sale, since current production has been largely in two or three research laboratories for use in alloying and other investigations.

physical metallurgy

Because of its extreme sensitivity to impurities, particularly the nonmetals, the properties of titanium depend greatly on composition. This makes it difficult to tabulate mechanical properties since variations in the method of preparation and handling give a wide range in values. Titanium produced by the iodide method is rather soft, varying from 60 to 90 Vickers; annealed bars or cast metal from magnesium reduced titanium powder usually runs from 180 to 220. Likewise, the tensile strength of worked and annealed iodide titanium may be around 37,000-45,000 psi with 35-45 per cent elongation; comparative values for the magnesium reduced product are about 80,000 psi and 25 per cent.

Titanium, like most useful metals, can be greatly hardened by cold work and softened by annealing. Iodide titanium may be cold worked to 99 per cent reduction without edge cracking; less pure metal cannot withstand such drastic cold work but can be hot worked or annealed



In its commercially pure form titanium is light, strong and has a high melting point, as illustrated above. It also has excellent corrosion resistance. It is expected to develop into a new family of structural materials.

at 650 C or over to permit additional cold working. A tensile strength of 125,000 psi, yield of 110,000 psi, and elongation of 12 per cent may be developed by a 50 per cent cold reduction of some magnesium reduced metal. Complete annealing is preferably done in vacuum since at 500-600C the metal forms an oxide coating and at 750C oxygen absorption becomes appreciable; in beta titanium, above 880C, oxygen absorption is very rapid. However, rapid annealing in air, as to permit more cold rolling, can be done as a practical measure without excessive oxidation or embrittlement.

Hot forging and rolling have become the most practical forming operations, with cold rolling used largely for finishing. Although titanium is one of the high-melting metals and reacts vigorously with practically everything at its melting point, recent development work has demonstrated the feasibility of melting it in a vacuum arc furnace. Usually, there is some loss in purity, as judged by hardness gain, but apparently, this can be kept within practical limits. This, then, overcomes the need for powder-metallurgy treatment of titanium powder. Eventually, large ingots should be available for forming large structural sections.

Titanium alloys readily with most metals. It is still too early to point out those alloy systems which will be of most future importance, since the addition of many metals exerts a profound influence on the properties. Indications are that the study of titanium alloys, as with iron, will be almost endless, and it is one of the richest present fields for physical metallurgy investigations. The fact that titanium has a phase transformation adds another factor to the possible effect of heat treatment on properties that can be developed. However, so far this has not given the promise that it will be anywhere nearly as important as the hardening of steel by heat treatment.

properties and uses

A few of the useful fundamental properties of titanium are given in the accompanying table. Ductile titanium of high purity has become available in fair quantity only recently, and many properties have not been investigated adequately to give definite values.

The strength-weight ratio for some of the alloys of titanium is high, well above that of any other structural material that has been listed. Moreover, the strength is retained rather well at moderately elevated temperatures where aluminum and magnesium alloys have lost much of their useful strength. Thus, at 800F the strength of 50 per cent cold worked magnesium reduced titanium sheet is still 53,000 psi in short time tests; the creep rate is about the same as for high strength aluminum alloys at 400F. There are rather good possibilities for developing high strength at high temperatures by alloying. These properties all point to applications as structural materials for aeronautical use.

Titanium can be hot forged, machined about as readily as austenitic stainless steel, and spot welded and arc welded in an inert atmosphere. Its high proportional limit has been cited as a definite advantage over stainless steel.

SOME PROPERTIES OF TITANIUM

Density, 20 C.	4.54
Melting Point	1725 C. (3240 F.)
Boiling Point	Above 3000 C. (5430 F.)
Specific Heat	0.142 Cal./g./C.
Coef. Linear Expansion	8.5 x 10^{-6} per C.
Thermal Conductivity	105 Btu/ft.^{2}/in./F./hr.
Elect. Conductivity	3.2% IACS
Allotropic Trans.	880 C. (1615 F.)
Structure, below 880 C.	C.P. Hexagonal
above 880 C.	B.C. Cubic

The corrosion resistance of titanium is good and is usually compared favorably with stainless steel. It is not attacked by the atmosphere, and has excellent resistance to sea water, humid and saline atmospheres, and nitric acid. Insufficient data are available to judge the position titanium and its alloys may occupy because of corrosion resistance, but it seems to be in the general class of chromium and nickel.

good combination of qualities

Ductile titanium, and what is known of its alloys, possess a good combination of strength, lightness, high proportional limit (particularly alloys), modulus of elasticity, and corrosion resistance. Special applications undoubtedly will be found because of these properties even at the present cost of the metal. As the cost is reduced with improved and larger scale production, titanium would be expected to compete strongly with other structural metals. A handicap for high temperature applications of which there are many at present, is the tendency for hot titanium to absorb oxygen, nitrogen, hydrogen, and carbon. Research is needed to overcome this by alloying or surface protection.

In comparing titanium with other metals, the properties of the pure metals or of their alloys should be compared, not those of the slightly impure titanium with highly developed alloys of other metals as is frequently done. The future of titanium is largely in its alloys, which offer excellent promise but about which almost nothing has yet been published.

conclusions

This, then, is the metal titanium—not a Cinderella or magic metal, but no parasite either that tags along as a minor addition to other metal bases. It can stand on its own feet as a metal base, and take a well deserved place with the other useful structural metals. No one who has worked with ductile titanium and investigated some of its alloys can escape the conclusion that here is a really good metal, and it's going to be fun to watch and participate in its rapid commercial development. For those of us who have preached the gospel of titanium for these many years it is most gratifying to see that the ball is rolling, that the development is in strong, capable hands and that enthusiasm is being tempered with caution.

Oxygen in Manufacturing Electric Furnace Steel

E F S C also hears Kellogg electric melting processes

There is probably no recent development in steel making which, after rocking badly on a stormy sea, has settled down so rapidly onto an even keel, as the use of oxygen for decarburizing a molten bath in the electric furnace. The original experimental work by Carnegie-Illinois Steel Corp. at South Works on lowering the melt-down carbon in 18 per cent chromium, 8 per cent nickel stainless steel resulted in the well-known Chelius patent (U.S. Patent 2,226,967, Dec. 31, 1940); and the procedure of burning out the carbon with an oxygen lance has been rapidly extended to other grades of steel, both in ingot-producing shops and in the melting of steel for castings.

The results secured at South Works on 50- to 80-ton basic electric-furnace heats of stainless, and on high-quality carbon- and low-alloy steels, were described a few months ago by J. H. Eisaman in a paper before the May 1948 meeting of the American Iron and Steel Institute. This work was summarized, and a considerable amount of additional information, for both basic and acid practice, was reported at the 1948 Electric Furnace Steel Conference of A.I.M.E., held in Pittsburgh on December 2-4, during which two full sessions were devoted to the subject.

The difficulties in attempting to produce, economically and satisfactorily, large heats of low-carbon 18-8 with ore as an oxidizing medium are numerous, and it is virtually impossible to use large quantities of stainless scrap in this practice. The reasons are obvious: chromium oxidizes preferentially to carbon at the low temperatures prevailing during and just after melt down, and this results in excessive loss of this element and in large slag volumes which are hard to handle. Scrap has to be carefully selected and prepared, and precautions must be taken to insure that extraneous carbon (oil or grease) is not present. Finally, in the decarburization of the bath by ore, high temperatures and relatively long heat times are necessary, which naturally reduce refractory life.

The use of oxygen largely overcomes these disadvantages. At the bath temperatures that prevail when the oxygen is introduced the gas reacts rapidly with carbon and not appreciably with chromium; a high percentage of stainless scrap may be used, the recovery of chromium is excellent, and slag volumes are relatively normal. The ultimate result, as compared with heats in which ore is used, is a marked increase in tons per hour, a decrease in heat time and power consumption, and lower material-handling costs.

J. E. Harrod, of South Works, reported at the Electric Furnace Steel Conference (for 44 consecutive heats averaging 83 tons) that chromium recovery in low-carbon 18-8, in which more than 50 per cent of light bundled stainless scrap was used, was 88 per cent. The average melt-down carbon was 0.16 per cent, and the average carbon reduction was 0.10 per cent. Approximately 164 cu. ft. of oxygen per ton was used, and the power consumption was 449 Kwhr. per (tapped) ton. Production per furnace hour was 7.23 tons.

On heats with a specified maximum carbon content of 0.07 or 0.08 per cent the average recovery of chromium from a charge of 50 per cent stainless scrap was 78 per cent, and approximately 350 cu. ft. of oxygen per ton was used.

The advantages secured by Mr. Harrod were confirmed at the Duquesne Works of Carnegie-Illinois by

Electric Furnace Steel Conference Dinner speakers' table at the Sixth Conference attended by 615, December 2-4 in Pittsburgh, Pa. (Left to right) Ernest Kirkendall, Secretary, E.F.S. Committee; C. A. Gordon, Vice Pres., Jessop Steel Co.; A. J. Scheid, Jr., President, Electric Melters Guild; Frank Lounsberry, Vice Pres. and Tech. Dir., Allegheny Ludlum Steel Corp.; Walter E. Baker, Vice Pres., Universal Cyclops Steel Co.; Norman I. Stotz, Chairman, E.F.S. Conference Committee; Gilbert Soler, Chairman, Iron and Steel Division, AIME; John B. Caine, Metallurgist, Sawbrook Steel Castings Co., Chairman, E.F.S. Executive Committee; Jimmy Arrington, Speaker; Hiland Batcheller, President, The Allegheny Ludlum Steel Corp., Toastmaster.

A. C. Ogan, who also reported at the conference data on the use of oxygen in melting nine grades of stainless. Charges containing as much as 100 per cent stainless scrap were used for heats of 0.12 per cent carbon and less, and up to 60 per cent stainless scrap was used for heats required to contain less than 0.08 per cent carbon. The percentage of carbon in the bath after using oxygen in approximately 150 heats averaged about 0.06 per cent, and values as low as 0.045 were not uncommon.

Some interesting results on the use of oxygen in melting high chromium-nickel steels for castings on an acid bottom were reported by R. J. Wilcox at the same meeting. With ore practice, it has been difficult to secure satisfactory results if more than 25 per cent stainless scrap was used; with oxygen, up to 75 or 85 per cent of this material could be charged. On 104 two-ton heats of 18-8 for castings, the melt-down carbon averaged 0.19 per cent; this was rapidly lowered to 0.07 per cent by the use of 496 cu. ft. of oxygen per ton of steel. Mr. Wilcox stated that 38 cu. ft. of oxygen per ton would remove 0.01 per cent carbon in an average time of 8.5 seconds.

He also reported comparative costs on the 104 heats using oxygen and on 41 heats in which the conventional ore practice was employed. The cost of the gas was $2.24 per ton of steel, but the net saving resulting from the use of oxygen was $1.54 per ton, accounted for primarily by a reduction of 20 per cent in power costs, 15 per cent in electrode consumption, and 17 per cent in man hours. Incidentally, this does not include the saving due to the greatly increased use of stainless scrap in the charge.

Harrod also gave some interesting data on the use of oxygen in melting 50-ton heats of AISI low-alloy double- and single-slag heats, and in producing 75-ton rimming-steel ingots. Up to 80 per cent alloy steel scrap was used, and enough carbon (as coke or high-carbon scrap) was charged so that the bath carbon was about 0.20 per cent above that required in the finished steel. The carbon was then lowered by oxygen to a percentage permitting high-carbon ferroalloys to be used. According to Harrod, the use of oxygen results in faster heats, more positive carbon removal and fewer off-quality steels, and higher residual manganese and chromium contents.

low hydrogen heats

Another advantage in the use of oxygen instead of ore as a decarburizer, which may soon prove to be the most important of all, is that it probably prevents the hydrogen content from rising to harmful levels. Both Harrod and Ogan in discussing the use of oxygen in stainless heats, commented on the absence of "back-up" or gassy ingots in the straight chromium grades. In using oxygen on low-alloy and on carbon grades Harrod noted further that in these steels the removal of carbon by oxygen seems to be the most reliable method of making a steel with an innocuous amount of hydrogen "because of decreased introduction of hydrogen and the purging action of the oxygen."

At the Burnside Steel Foundry, Chicago, C. H. Wyman and his associates made a test run on the use of oxygen for carbon removal in 101 carbon-steel acid heats of about 5 tons each. The data on these, also reported at the Pittsburgh conference, were compared with similar heats that had been produced over a previous 4-month period by using ore, and with 450 heats made later in which oxygen was used as a regular procedure. It was found that about 4 cu. ft. of oxygen was necessary to remove one ton-point of carbon. The rate of carbon removal was definitely related to the FeO content in the slag and the manganese content of the bath when oxygen injection was begun. During the period of oxygen use, the FeO content of the slag decreased steadily.

Bath temperatures increased sharply during the time the oxygen was being used, resulting in an overall net decrease in power consumption of the order of 7 per cent. The use of oxygen apparently had no untoward effect on furnace refractories, and the fluidity of the metal as it was poured into the molds was higher than when ore was used. The overall saving, owing to the use of oxygen, was just slightly less than $1.00 a ton.

The quality of a heat of steel is an elusive characteristic, impossible to define unless definite criteria are used to establish a norm. It is apparent, however, from the papers and discussion at the Electric Furnace Steel conference that the overall quality of oxygen-treated steel is no lower, but probably considerably higher, than the quality of steel in which ore is used for deoxidation. If low hydrogen is taken as a criterion of quality, oxygen-treated steel is certainly far superior to steel of otherwise similar composition made by more orthodox methods.

(Left to right) Floyd Rose, Chairman of the Board, Firth Sterling Steel & Carbide Co.; T. J. McLaughlin, Assistant to the Vice-Pres., Carnegie-Illinois Steel Corp., Vice-Chairman elect of the Conference Committee; B. Maloney, Works Manager, American Steel Foundries; S. B. Minton, President, Vulcan Crucible Steel Co.; W. J. Reagan, Past Chairman E.F.S. Executive Committee; J. A. Bowers, Vice-Chairman E.F.S. Conference Committee.

Kellogg Special Electric Melting Processes Told

Another feature of the 1948 conference on electric furnace steel, that attracted a large audience, was the session on Friday morning December 3; this was devoted solely to a report on recent developments at the Jersey City plant of M. W. Kellogg Co., in the production of composite steels, in the continuous electric melting and casting of pipe-free ingots of high-alloy steel, and in the perfection of an electric hot top to increase ingot yield and reduce cost. Three papers were presented by R. K. Hopkins, manager of the electric production department of the Kellogg Co., and a lively discussion resulted. The complete papers, giving all of the experimental data, and the discussion, will be published in the 1948 *Proceedings*.

In the first paper Hopkins gave details of the production of composite steels, which has been practiced successfully for some time at the Brackenridge plant of Allegheny-Ludlum Steel Corp. Known by the trade name Pluramelt, the process is an economical method of preparing plate or sheet for fabricating pressure vessels or other articles, which have a heavy inner coating of high-chromium, or austenitic chromium-nickel (18-8) steel on a carbon-steel backing.

The operation consists essentially of the controlled feeding of the alloying elements—ferrochromium, ferromanganese, nickel, or others—through tubular electrodes (formed from carbon-steel strip by rolls in the machine) onto the surface of a carbon-steel slab where it is arc fused to produce molten metal of the composition desired. The fused layer is adherent and essentially free from segregation and non-metallic inclusions. The thickness and width of the deposited high-alloy material can be readily controlled so that the composite slab can be rolled to plate or sheet of the desired thickness in one heating.

Despite the fact that the transition in structure from the carbon-steel backing to the high-alloy facing material is not gradual, the bond is perfect, and the composite steel meets the required bend-test, punch-test, and tensile-test requirements consistently. The composition of the facing does not vary appreciably; for example, the chromium concentration of a typical composite material was 18.3 per cent near the surface, 18.1 per cent 1 in. below, and 18.2 per cent 1¾ in. below the surface. The corrosion resistance of the high-alloy material is the same as for a regularly melted steel of comparable composition.

According to Hopkins, thousands of tons of Pluramelt have been fabricated into pressure vessels and household utensils of various sizes and shapes and are giving complete satisfaction even at comparatively high temperatures and under heavy loads. During the late war the process was widely used for producing face-hardened armor for gun shields on warships and protecting aircraft crews.

electric-ingot process

The electric-ingot process is a development that apparently grew out of the work on composite materials. Alloy steels of any composition are made by this process, which consists essentially of arc melting in a water-cooled mold a tube of low-carbon steel through which the alloying elements are fed to the molten metal. The tube is formed continuously from a coil of strip by a series of rolls mounted in the machine just above the mold and the finely-crushed alloying metals feed into the tube from a hopper located just above the rolls. The metering devices for the alloying metals, and the rolls, are operated by the same motor, which makes synchronization and exact proportioning simple. The process is started by placing a small quantity of the properly mixed alloying materials in a depression in the stool thus enabling the arc to be started readily.

Round ingots in a wide range of diameters and lengths can be made. The metal fuses rapidly and the solidification rate can be closely controlled by balancing the heat input of the arc and the heat loss from the water-cooled mold. The feeding mechanism is, of course, ideal for exactly counteracting volume changes during solidification and the resulting ingot is free from either primary or secondary pipe, internal bursts, or segregation. There are virtually no melting losses.

Hopkins gave as a typical illustration the production of 400-lb. ingots, 9 in. in diameter and 21 in. long, of a gas turbine alloy containing 0.05 per cent carbon, 1.35 per cent manganese, 16.3 per cent chromium, 25.5 per cent nickel, 6.2 per cent molybdenum, and 0.16 per cent nitrogen. The as-cast structure was remarkably uniform and carbides were well dispersed. In a heat of 18-8 to which lead was added to improve machinability there was no segregation and the lead particles, moreover, were dispersed in the austenite grains and were not located at the boundaries.

Mechanical properties of steel cast by the electric ingot process are excellent and the ductility of specimens taken in a transverse direction to the major axis of the ingot is much higher than is customary for similar specimens of the same alloy cast conventionally. The process has been used for a large number of high-alloy steels for gas turbine parts and for hundreds of tons of high-speed tool steel, all of which was rolled directly to billets and bars with no intermediate forging.

At present work is under way toward applying the process to making duplex turbine wheels which have a central section of heat-treatable (martensitic) steel and a rim of heat-resisting austenitic material.

the electric hot top

The electric hot top was developed in an effort to increase the yield of high-quality steel ingots and to eliminate primary and secondary pipe. Actually no hot top, in the usual sense of a refractory, or refractory-lined, collar placed on the mold is used; on the contrary the ingot mold is filled, powdered slag of special composition is placed on the top of the molten metal while heat to melt the slag and keep it molten is supplied by the arc from an automatically controlled electrode.

The composition of the slag used is important to the successful carrying out of the operation, and this must be tailored to fit the composition of the steel being made. Electrodes are water cooled and are not consumed. Power consumption varies from 15 to 30 Kw. hr. per net ton and the average over a year with 9 to 16-in.-square ingots was 20 Kw. hr. Hopkins claimed that operating cost including amortization, labor, and materials was approximately the same as the cost of using refractory hot tops.

Advantages claimed for the Kellogg electric hot top are higher yield—Hopkins reported an average of 92.3 per cent for 109 heats of high-alloy steels—from ingots to billets; and a relatively constant yield over a long period of time regardless of wide variation in teeming temperatures.

LETTERS TO THE EDITOR

Powder Metallurgy Paper

The following communication involves the paper, "Powder Metallurgy of Porous Metals and Alloys Having Controlled Porosity," by Pol Duwez and Howard E. Martens, before the Institute of Metals Division at New York in February, 1948, and published in Metals Technology, April, 1948. Coming to us too late for a printed discussion, we have incorporated it as a "letter."—Editors.

This paper states that the proposed method of "sweat cooling" was devised in September, 1944, at the jet propulsion laboratory, California Institute of Technology, and that the work, presumably of high urgency from the military standpoint, was carried out under contract with Army Ordnance Dept., Washington, D. C., and the Air Materiel Command, Army Air Force, Wright Field, Ohio. [Since this letter was first written, the Army Ordnance Dept. has advised that this project originated with the Navy.]

We must take exception to the alleged date of conception, for our own patents were issued well before then. The basic patent for the use of a coolant moving in a direction opposite to that of the heat flow, was U. S. Pat. No, 2,215,532, "Method and Apparatus Relating to Insulated Vessels and Structures of Great Variety," issued to Edward Adams Richardson, Sept. 20, 1940. A patent involving the use of fluid permeation through the walls of a furnace, U. S. Pat. No. 2,311,350, "Method and Apparatus for Controlling Combustion," was issued to him Feb. 16, 1943. The concept of the use of permeable metals for such things as gas turbine blading with what is now described as "sweat cooling" and for other purposes, in which the additional feature of the slowly outward moving laminar flow layer is utilized for limiting, or preventing heat flow to the body by either conduction or convection or both, was fully known to us earlier and is recorded.

Likewise the original patent and other work done were brought to the attention of the armed services in 1942 and the National Inventors Council. In every case, the ideas were rejected as being of no use.

So far as the present paper is concerned, useful data have been secured, and the authors are to be commended. Any attempt to limit the investigation of materials to be used in "sweat cooling" to powder metal compacts compressed at high pressure further endangers the military security. The size of the parts required demands more attention to means for producing sintered bodies formed without high pressure compaction and with the use of the simplest molds and dies. Large parts cannot be made in quantity by the methods proposed.

As to Fig. 5, small particles tend to agglomerate into large particles, presumably below normal sintering temperatures, and this process is irreversible. The powder used had 24.4 per cent by weight coarser than 325 mesh, the balance through 325 mesh; hence there was ample reason to expect the behavior from A to B to T_4. Below the lowest resulting sintering temperature, presumably T_5, cooling should give a solid metal type of contraction curve in view of such irreversibility.

The conclusion that ultimate strength is a simple function of porosity, and hence of ammonium bicarbonate content, is misleading in that only one size and particle size distribution was used for stainless steel; another for each of the other alloys. In view of the interpretation given for Fig. 5, a change in particle size distribution might well produce variations of great importance. Furthermore the strength for a given powder is a function of the porosity, the elongation for a given porosity is much better at the higher sintering temperatures, of great importance in forming parts subjected to dynamic loading. It is unfortunate that the use of nitrogen gas as a neutral atmosphere was not investigated, both for comparison with hydrogen and helium.

It is desirable to use a permeability coefficient in the general manner of Equation 1. It is good to have some data on the limits of the Darcy law with rate of flow for such compacts. Failure to carry the experiments on the ammonium bicarbonate filler to compacts sintered under zero pressure is unfortunate, since this region may prove of the greatest importance. The inclusion of porous bronzes is misleading since they were not formed from powders of the same sizing. Here again the effect in Fig. 5 may make its appearance as particle sizes, or their distribution, or both are varied. Points 3 and 4 could easily lie on a curve in Fig. 19 paralleling iron, while points 1 and 2 are more likely determined by separate curves. *Each material and particle size distribution would lead to a separate curve in Fig. 19.*

In view of the Fig. 5 effect, variation in the proportion of fine particles, perhaps more particularly the variation in sizing in the fine particle portion, may lead to definite variations in the behavior of a powder. The Fig. 5 effect is merely a specific case of the principle that large particles tend to grow at the expense of small particles, large crystals at the expense of small.

The ability to specify strength and permeability for a given part is important. The results secured in these tests are not sufficient to warrant dependence on one particle size to the neglect of the effect of particle size, however. Unfortunately, it is not the initial but the final particle size, after sintering, that is important, and this will depend upon the temperature-time regime used.

In this paper no attention has been given to the effects of lubricant in modifying compaction with such means as tamping the powder in layers to avoid the necessity for the high pressures actually used. It is well known from soil mechanics that variations in a lubricant such as water, in terms of proportion of water to granular body, lead to some four distinctive regions of density for a given amount of tamping. When sudden expansion of military production for large parts is required, it is essential that the techniques available shall be adapted to such expansion with the minimum of capital requirements.

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Metal Branch Programs at San Francisco

A tentative program of technical papers for the metals divisions of AIME at the annual convention at San Francisco at mid-February has been prepared. These technical sessions will extend over four days, Monday to Thursday, Feb. 14-17, usually at the Mark Hopkins Hotel, across the street from the Fairmont Hotel which serves as headquarters.

Extractive Metallurgy

Monday Afternoon

LEAD AND ZINC

Electrolytic Zinc Plant at Risdon, Tasmania — Major Changes since 1936, by S. W. Ross.

Fire Metallurgy of Cadmium, by George T. Smith and Robert C. Moyer.

The Recovery of Cadmium from Cadmium-copper Precipitate, by G. H. Anderson.

Cadmium Recovery Practice in Lead Smelting, by P. C. Feddersen and Harold E. Lee.

The Zinc and Lead Industry in Germany Today by T. Benson Gyles.

Tuesday Morning

LEAD AND ZINC (cont.)

The Effect of High Copper Content on the Operation of a Lead Blast Furnace, and Treatment of the Copper and Lead Produced, by A. A. Collins.

Oxygen-enriched Air in the Lead Blast Furnace and Slag Fuming Furnace, by R. R. McNaughton and Associates.

Concentration of the SO_2 Content of Dwight-Lloyd Sintering Machine Gas by Recirculation, by W. S. Reid.

Autogenous Roasting of Low Grade Zinc Concentrate in Multiple Hearth Furnaces at Risdon, Tasmania, by J. A. B. Forster.

Tuesday 12:15 p.m.

METALS BRANCH LUNCHEON

Wednesday Morning

ROUND TABLE SESSION

Discussion on Blast Furnace Charge Preparation and Dross Treatment, organized by R. R. McNaughton.

Sinter Feed Preparation, introduction by Casper Nelson and Bullion Dross Treatment, introduction by A. A. Collins.

Wednesday Afternoon

RETORTS AND EQUIPMENT

Development of the Modern Zinc Retort, by H. R. Page and A. E. Lee, Jr.

Controlled Drying of Retorts, by R. R. Furlong and Donald Wertz.

Development of Muffle Furnaces for the Production of Zinc Oxide and Zinc at East Chicago, by Gunnard E. Johnson.

El Paso Slag Treatment Plant, by T. J. Woodside.

Thursday Morning

TITANIUM

Joint Session with Industrial Minerals and Iron and Steel Divisions.

Melting Points in the System TiO_2-CaO-MgO-Al_2O_3 by H. Sigurdson and Sanford S. Cole.

Smelting of Titaniferous Ores, by David L. Armant and Sanford S. Cole.

Petrology of High Titanium Slags, by Charles H. Moore, Jr., H. Sigurdson and D. L. Armant.

The Pilot-plant Smelting of Ilmenite in the Electric Furnace, by C. Kerby Stoddard, Sanford S. Cole, and C. W. Davis.

Thursday Afternoon

COPPER AND ALUMINUM

The Morenci Smelter of Phelps Dodge Corporation at Morenci, Ariz., by L. L. McDaniel.

Continuous Casting — the Asarco Process, by J. S. Smart, Jr.

Distillation of Zinc from Copper-base Alloys and Galvanizers' Drosses, by Frank F. Poland.

Reflection on the Electrolytic Cells Used in the Production of Aluminum, by Bruno B. A. Luzzatto.

ISD Tentative Program

The Howe Memorial Lecture by Dr. John Chipman is scheduled for 11 a.m. Wednesday, Feb. 16.

Monday Morning

SULPHUR IN THE COKE OVEN AND BLAST FURNACE

Tracer Study of Sulphur in the Coke Oven, by S. F. Eaton, R. W. Hyde and B. S. Old.

Some Correlations Between Variables Affecting Sulphur in Blast Furnace Iron, by T. E. Brower and B. M. Larsen.

Sulphur Equilibria Between Iron Blast Furnace Slags and Metal, by G. G. Hatch and John Chipman.

Monday Afternoon

STEELMAKING

Relation Between Chromium and Carbon in Chromium Steel Refining, by D. C. Hilty.

The Effect of Hydrogen on the Ductility of Cast Steels, by C. E. Sims, G. A. Moore, and D. W. Williams.

The Origin of Silicate Inclusions in Basic Electric-arc-furnace Steel of Higher Carbon Contents, by Axel Hultgren.

Tuesday 12:15 p.m.

METALS BRANCH LUNCHEON

Tuesday Afternoon

PYROLYSIS, AGGLOMERATION

There will be a joint session with the Minerals Beneficiation Div. on Pyrolysis and Agglomerations. Among the papers will be one by Alan Stanley and J. C. Mead on Sintering Characteristics of Minus Sixty-Five and Twenty Mesh Magnetite.

Wednesday Morning

GENERAL SESSION

A brief Iron and Steel Div. Business Meeting, with Gilbert Soler, chairman, will precede the formal program.

The Influence of Temperature on the Affinity of Sulphur for Copper and Manganese, by E. M. Cox, M. C. Bachelder, N. H. Nachtreib and A. S. Skapski.

The Manufacture and Properties of Clad Steels, by T. T. Watson.

Wednesday Afternoon

STEELMAKING

The Role of Thermochemical Factors in Basic Open Hearth Production Rate, by T. E. Brower and B. M. Larsen.

The Interaction of Liquid Steel with Ladle Refractories, by C. B. Post and G. V. Luerssen.

The Relative Deoxidizing Powers of Some Deoxidizers for Steel, by C. E. Sims.

The Ionic Nature of Metallurgical Slags: Simple Oxide Systems, by John Chipman and Lo-ching Chang.

Thursday Morning

TITANIUM

A Titanium session jointly sponsored by the Extractive Metallurgy Division and the Industrial Minerals Division Thursday morning Feb. 17 has been outlined on Page 14.

by-laws considered

At the business meeting it has been proposed to amend the Iron and Steel Division by-laws, article 5 section 5, to permit the re-election of vice-chairmen.

IMD Probable Program

The Institute of Metals Division annual lecture by Professor Egon Orowan of the University of Cambridge in England is scheduled for 11:00 a.m. Tuesday, Feb. 15.

Monday Morning

PHASE DIAGRAMS

Platinum-Tungsten Alloys by R. I. Jaffee and H. P. Nielsen.

On the Structure of Gold-silver-copper alloys, by J. G. McMullin and J. T. Norton.

Use of Electrical Resistance Measurements to determine the Solidus of the Lead-tin System, by Ralph Hultgren and S. A. Lever.

Monday Afternoon

GRAIN BOUNDARIES AND SURFACES

The Effect of Orientation Difference on Grain Boundary Energies, by C. G. Dunn and F. Lionetti.

Influence of Composition on the Stress-Corrosion Cracking of Some Copper-base Alloys, by D. H. Thompson and A. W. Tracy.

Oxide Films Formed on Metals and Binary Alloys—An Electron Diffraction Study, by J. W. Hickman.

Tuesday Morning

BUSINESS MEETING AND LIGHT METALS

I.M.D. Business Meeting, A. A. Smith, Jr., Chairman.

Preparation and Properties of Magnesium-Lithium Alloys, by J. H. Jackson, P. O. Frost, A. C. Loonam, L. W. Eastwood and C. H. Lorig.

Hydrogen in Aluminum, by Y. Dardel.

Tuesday 12:15 p.m.

METALS BRANCH LUNCHEON

Tuesday Afternoon

PLASTIC DEFORMATION AND TEMPER BRITTLENESS

Plastic Deformation Waves in Aluminum, by A. W. McReynolds.

Homogeneous Yielding of Carburized and Nitrided Single Iron Crystals, by A. N. Holden and J. H. Hollomon.

The Effect of Strain-Temperature History on the Flow and Fracture Characteristics of an Annealed Steel, by E. J. Ripling & G. Sachs.

Temper Brittleness of Plain Carbon Steels, by L. D. Jaffe and D. C. Buffum.

Wednesday Morning

GRAIN GROWTH AND TEXTURES

Some Factors Affecting the Rate of Grain Growth in Metals, by J. E. Burke.

Preferred Orientation in Rolled and Recrystallized Beryllium, by A. Smigelskas and C. S. Barrett.

A Study of Textures and Earing Behavior of Cold-rolled (87-89%) and Annealed Copper Strips, by Ming-Kao Yen.

Wednesday, Feb. 16, 12:15 p.m.

IMD EXECUTIVE COMMITTEE LUNCHEON AND MEETING

Wednesday Afternoon

POWDER METALLURGY

Pressure Distribution in Compacting Metal Powders, by Pol Duwez and Leo Zwell.

Lead-Grid Study of Metal Powder Compaction by R. Kamm, M. A. Steinburg and J. Wulff.

Properties of Chromium Boride and Sintered Chromium Boride, by S. J. Sindeband.

Solubility Relationships of the Refractory Monocarbides, by J. T. Norton and A. L. Mowry.

Thursday Morning

POWDER METALLURGY SYMPOSIUM ON SINTERING

The Magnetic Properties of Sintered Iron and Iron Base Alloys, by W. Rostoker.

The Densification of Copper Powder Compacts in Hydrogen and in Vacuum, by C. B. Jordan and Pol Duwez.

The Surface Tension of Solid Copper, by H. Udin, A. J. Shaler and John Wulff.

Self Diffusion in Sintering of Metallic Particles, by G. C. Kuczynski.

Thursday Afternoon

POWDER METALLURGY SEMINAR ON SINTERING

Lead-off paper by A. J. Shaler, of Massachusetts Institute of Technology.

The deadline for Fall Meeting papers of IMD will be May 1, 1949.

For complete information write for Bulletin No. 206

BURRELL TECHNICAL SUPPLY CO.

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Working the Heat Dealt With by Chicago NOHC

The first session for the winter season, 1948-1949, of the Chicago Section, AIME, was held at Phil Schmidt's Oct. 25. The meeting was devoted to furnace practices and each district plant represented assigned a melter to present a short paper on "Working the Heat," and emphasizing the following points: Preferable carbon melt, rate of carbon elimination, slag control, control of phosphorus and sulphur elimination, temperature control, deoxidation practices, and methods used to control elements for analysis.

The formal program lined up as follows: High Carbon Heats, J. Sweeney, Carnegie-Illinois Steel Corp., Gary Works; Blocked Versus Open Tapped Forging Steel, C. Murton, Wisconsin Steel Works; Low Carbon Rimmed Steel, G. Goetz, Youngstown Sheet & Tube Co.; Low Carbon Rimmed Steel, J. Ropes, Continental Steel Corp., Chicago; Forging (0.25-0.45 C) Killed Steel, T. Lally, Republic Steel Corp., Chicago; Semi-Killed and Alloy Steel, R. Gonya and G. Maley, Carnegie-Illinois Steel Corp., South Works.

There followed a short presentation on "Training Personnel for the Open Hearth" by J. Ojala, Carnegie-Illinois Steel Corp., Gary Works.

The quality of the papers and discussions was excellent throughout, also reflecting credit on R. Dwyer, technical chairman. The attendance of 154 was made up of operating and staff members of seven district plants. The next session will be held in January and will be devoted to the discussion of pouring pit practice by pit foremen of each district plant, with G. E. Gustafson, Carnegie-Illinois Steel Corp., South Works, as technical chairman.

—M. F. Yarotsky

Prizes Given Warchol By Eastern Section NOHC

An all-day, off-the-record technical meeting, followed by a fellowship dinner in the evening was the schedule of the AIME Open Hearth Committee, Eastern Section, at the Warwick Hotel, Philadelphia, Nov. 5. The events were opened by a short address by T. T. Watson, Lukens Steel Co., Chairman, Eastern Section. Papers dealing with production problems were presented and discussed, the main topics having been bottoms, effect of hot metal quality on production, scrap preparation, charging practice and checker practice.

In the afternoon the topics were furnace construction, fuels, and quality. Chairmen for the meeting were: R. D. Zweier, asst. open hearth superintendent, Bethlehem Steel Co., Sparrows Point, Md.; D. R. Matthews, open hearth superintendent, Alan Wood Steel Co., Conshohocken, Pa.; H. S. Hall, fuel engineer, Lukens Steel Co., Coatesville, Pa., and C. F. Chandler, engineer of tests, Bethlehem Steel Co., Steelton, Pa.

J. A. Warchol, research engineer, Lukens Steel Co., read his prize-winning paper, "Factors Affecting the Quality of Rimming Steel Ingots" and at the dinner he was presented with a $50 savings bonds by Chairman Watson and with a check for $100 by D. Watkins, publisher, *Blast Furnace and Steel Plant Magazine*. The guest speaker was H. Haines on professional athletics.

—T. T. Watson

Army Reserve Commissions, Metallurgical Engineers

Reserve commissions in the Army of the United States are now available to qualified metallurgical engineers who meet the requirements of age, education, experience and physical condition. The commissions range from those of First Lieutenant up to and including full Colonel, depending on the qualifications and experience the metallurgical engineer possesses in his specified field. Applicants must be at least twenty-one (21) years of age for appointment in the Reserve Corps, and applications will be considered from individuals up to fifty-five (55) years. All must be citizens of the United States. No previous military experience is required.

Contact the Adjutant General, Department of the Army, Washington 25, D. C.

SMELTS and SMILES

By Edgar Allen, Jr.

HOTEL RULES
JUST MARRIED!
EDGAR ALLEN JR.

"I was just mentioning in the continuous casting of steel, proper cooling of the mold is essential and its importance increases as the casting rate is increased—"

Pittsburgh AIME Deals With Several Topics

An "off-the-record" meeting of the Pittsburgh section, AIME, was attended by 680 persons on Nov. 12 under the direction of R. F. Miller, Carnegie-Illinois Steel Corp., and G. R. Fitterer, University of Pittsburgh. The subject matter of the discussions represented a good cross section of AIME interests. Only Metal sessions are reported here. Since the program was an off-the-record affair, no attempt was made to take notes of discussions. Each session was lively and widely participated in by discussers. Present were 135 students from University of Pittsburgh, Carnegie Institute of Technology, University of West Virginia and Pennsylvania State College.

An operating session of the Pittsburgh Section of the N.O.H.C. was held under the co-chairmanship of Henry Warren and Charles Witherspoon, dealing with the following topics: What we can expect of fuel oil in the future, economics of scrap segregation and preparation and its effect on production, and rammed mixers.

Eight topics were discussed at the Acid Open Hearth session under the co-chairmanship of R. M. Barnhart and R. C. Heaslett: Superiority of acid open hearth steel over basic open hearth steel; present sulphur limits in A.S.T.M. and S.A.E. specifications are lower than necessary for quality steels; light scrap affects the working of the heat but not the quality of the product; pig iron substitutes produce acid steel of quality equal to pig iron heats; the viscosimeter is an unfailing guide to the progress of an acid heat; an acid heat of go-ahead 0.03-0.05 silicon makes steel inferior to one of 0.10-0.15 silicon; ladle deoxidation produces inferior steel; the mechanical properties of 0.30 carbon steel are unaffected by wide variations in carbon drop before block.

The refractories session was in charge of Ernie Snyder and Messrs. Strother and Fairchild, discussing: Relation of combustion and downstairs refractory life; slag pocket, fantail and arch construction, life and repairs, and open hearth checkers. Each subject precipitated much discussion, equal to any "old time" open hearth meeting.

The Metallurgy session of the Pittsburgh Section of the N.O.H.C. was conducted by S. J. Dougherty and W. J. Reagan, the meeting considering three subjects: The effect of various amounts of sulphur on the surface of all types of products made from low carbon rimmed steel, capped steel, semi-killed steel and fully-killed steel; the enumeration of surface defects in hot rolled and cold reduced sheets attributable to open hearth furnace, ladle, mold and soaking pit practices, with recommended remedies in low carbon rimmed steel, capped steel, semi-killed steel and fully-killed steel; the mechanical capping of steel and its effect on the surface of all products.

institute of metals session

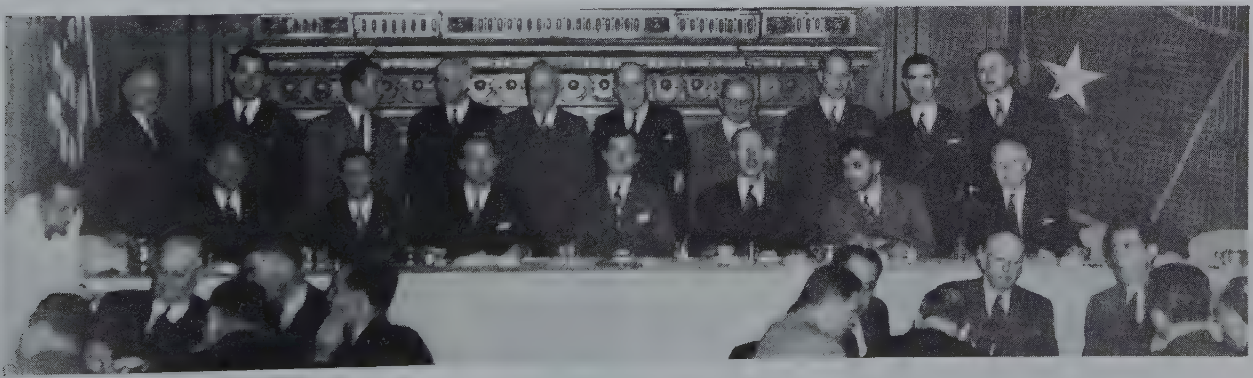
The Institute of Metals Division conducted a 4-point program under the chairmenship of F. C. Hull and G. E. Pellissier. They dealt with: Stability of stainless steels at elevated temperatures, the hardenability effect of molybdenum, the effect of ferrite grain size on notch toughness, and the diffusion and solubility of carbon in alpha iron.

The meeting was concluded with a cocktail party through the courtesy of the Suppliers' Group of the Pittsburgh area under the chairmanship of R. S. Runyon and a fellowship dinner, whose main speaker was Joseph E. Thornton, special agent in charge, Pittsburgh office, Federal Bureau of Investigation, who gave an interesting talk on his personal experiences as an F.B.I. agent.

—**Hugo E. Johnson**

Solid State Physics Div.

The annual meeting of the Division of Solid State Physics, American Physical Society, will be held Thursday, Friday and Saturday, March 10-12, in Cleveland. Members should make reservations at the Hollenden Hotel, Cleveland, not later than March 1.



Seated (left to right) E. H. Robie, Acting Secretary, AIME; A. W. Thornton, Chairman, Pittsburgh Section, NOHC; J. E. Thornton, Special Agent in Charge, FBI, Pittsburgh, speaker; L. Thiessen, Toastmaster, Chairman, Pittsburgh Section, AIME; Dr. L. E. Young, President Elect, AIME; M. Tenenbaum, Winner, 1948 NOHC Pittsburgh Section award; Richard Maize, Secretary of Mines, Pennsylvania. Standing (left to right), R. S. Runyon, Chairman, Suppliers Cocktail Party Committee; T. Merrill, Chairman, Pittsburgh Chapter, ASM; G. R. Fitterer, Chairman, Program Committee, NOHC, Pittsburgh Section; C. Longenecker, Secretary, Pittsburgh Section, NOHC; Newell G. Alford, Director, AIME, Charles FonDersmith, Chairman, NOHC; H. P. Greenwald, Vice Chairman, Pittsburgh Section, AIME; E. O. Kirkendall, Asst. Secretary, AIME; R. F. Miller, Chairman, Program Committee, Pittsburgh Section, AIME; Hugo E. Johnson, Executive Secretary, NOHC, Pittsburgh Section.

Engineering Societies Personnel Service, Inc.

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Detroit—100 Farnsworth Ave.
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These items are from information furnished by the Engineering Societies Personnel Service, Inc., which is under the joint management of the four Founder societies. This Service is available to members and is operated on a co-operative, nonprofit basis.

In applying for positions advertised by the Service, the applicant agrees, if actually placed in a position through the Service as a result of these advertisements, to pay a placement fee in accordance with the rates as listed by the Service.

When making application for a position include six cents in stamps for forwarding application to the employer and for returning when necessary.

All replies should be addressed to the key numbers indicated and mailed to the New York office.

A weekly bulletin of engineering positions open is available to members of the co-operating societies at a subscription of $3.50 per quarter or $12 per annum, payable in advance.

Positions Open

RESEARCH ENGINEER, capable of taking charge of research program concerned with the fracture and ductility properties of steel. Opportunity to work for advanced metallurgical or civil engineering degree. Metallurgical training desirable. Salary up to $3600 depending on experience. Write stating personal, education and experience data. Location, Pennsylvania. Y1376.

INSTRUCTOR to teach forging, welding and machine shop. Salary, about $3000 for nine months. Temporary. Location, Colorado. Y1469S.

ASSOCIATE PROFESSOR, with Ph.D. in optical mineralogy and ceramic petrography, and some practical experience in petrography and ceramic petrography. Salary, $4500 for nine months. Location, Missouri. Y1497C.

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GENERAL MANAGER, 35-45, with malleable iron foundry and machine shop experience, to supervise operations for manufacturer of pipe fittings. Knowledge of Portuguese or Spanish desirable. Salary, approximately $8000 a year. Location, Brazil. Y1526.

RESEARCH METALLURGIST, non-ferrous, to direct a small department in a large manufacturing company. Salary, up to $7200 a year. Location, New York Metropolitan Area. Y1591.

METALLURGIST, with four years' engineering college, B.S. degree and three to four years' experience, with knowledge of metallurgy, physics, metallography, electronics, industrial X-ray methods and analysis, interpretating radiographs to detect sub-surface irregularities and defects of purchases parts, castings and forgings. Location, Connecticut. Y1676.

METALLURGIST, 35-45, preferably married, graduate, experienced in the non-ferrous field. Should be qualified to perform research on experimental alloys, and should be useful in working out new methods. Should be acquainted with all kinds of metallurgical problems in the ferrous as well as non-ferrous fields. Prefer resident of northern New Jersey. Y1715.

ASSISTANT GENERAL FOREMAN, preferably with metallurgical training and some copper casting experience for furnace refinery department. Will be required to supervise casting operations, breaking in men, schedule furnace castings and repairs, and handle labor and the ordering of supplies. Starting salary, $4500 a year. Location, Texas. Y1755S.

METALLURGIST or METALLURGICAL ENGINEER, graduate, to perform metallographic and other laboratory duties, covering ferrous and non-ferrous pipe, plate, castings, welding, corrosion, etc. Salary, $3000-$3600 a year. Location, Massachusetts. Y1758.

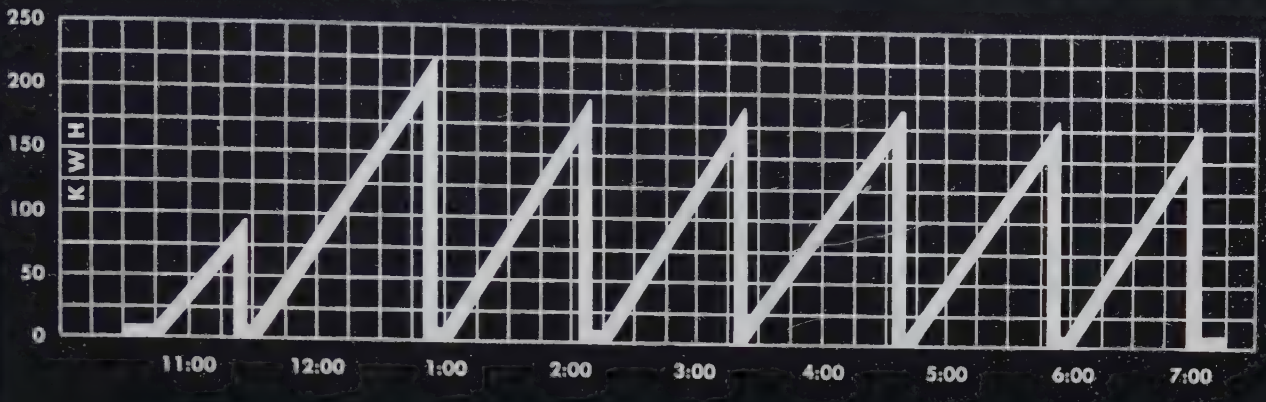
SENIOR METALLURGIST, 25-40, with engineering degree in metallurgy, with three to five years' industrial experience, preferably aircraft, and experience in engineering applications of aircraft materials, trouble shooting and service analyses, quality control of aircraft materials and processes. Salary, $3500-$6500 a year, depending upon qualifications. Location, Conn., Y1772.

METALLURGICAL ENGINEERS, 23-40, to train for openings in research, quality control and technical field service with company engaged in manufacturing and marketing of stainless, mild and alloy steel arc welding electrodes. All positions require academic training and industrial experience. Salary dependent upon qualifications. Location, Pennsylvania. Y1859.

ASSISTANT EDITOR, 25-30, metallurgical graduate, with three to five years'

(*Continued on Page* 20)

DETROIT ROCKING ELECTRIC FURNACE



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Besides optimum power use, all-electric operation precludes handling and storing messy, bulky fuels. Equally advantageous is the positive control of operational speed, composition quality and other melting factors. Out-of-production time due to burned-out linings is minimal. Spare, previously-lined furnace shells are quickly, easily installed.

Other saving features are fast, uniform outputs; lowest metal loss by shrinkage; conversion of shop borings and turnings with least loss from oxidation. The arc is automatically established clear of the molten bath at all times. The metal is never a part of the electrical circuit, assuring uniform temperatures within the melting chamber.

Detroit Rocking Electric Furnaces are available in 10 to 4000 lb. capacities with either conical or cylindrical chambers. Individually designed to meet your plant electrical specifications.

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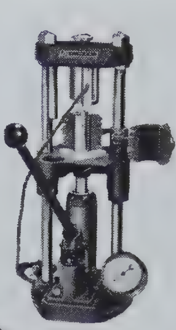

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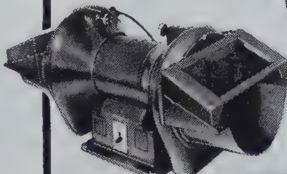

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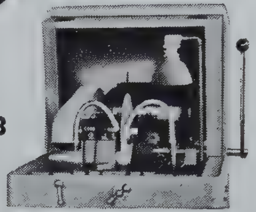

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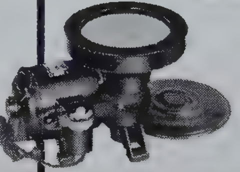

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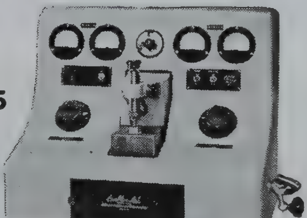

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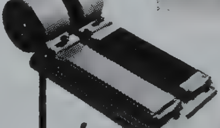

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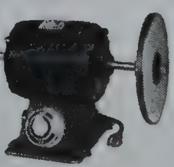

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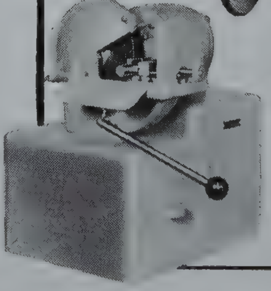

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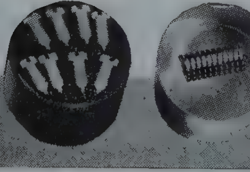

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experience in ore dressing or non-ferrous smelting, to prepare and edit technical articles in mining and metallurgical field and visit mining operations to collect data. Knowledge of photography desirable. Salary, $4800-$5400 a year. Location, New York, N. Y. Y1798.

ENGINEERS. (a) Metallurgical Chemist with at least five years' experience covering melting of nickel and alloys. (b) Metallurgical Superintendent with secondary smelting experience, to supervise operations of oil-fired rotary, reverberatory furnaces. Salary, $4200-$4800 a year. Location, New Jersey. Y1886.

RESEARCH PHYSICAL METALLURGIST, young, with Ph.D. in metallurgy for a long term fundamental study in the non-ferrous field. Scope of work extends into relatively new and little-explored regions where the opportunities for both scientific and technical contributions are good. For a man interested in physical metallurgy research the proposed work offers interesting and challenging possibilities. Position requires that the individual have a good fundamental and theoretical background combined with good experimental aptitude. Some experience in experimental work is necessary and applicant should be of the "research" type. Location, Connecticut. Y1889.

GENERAL MANAGER, graduate metallurgical engineer, with considerable experience in the roasting of ores and purification of metals, particularly tungsten or cobalt. Salary, $8000-$10,000 a year plus bonus. Location, northern New Jersey. Y1871.

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POWDER METALLURGIST, graduate chemical engineer, 35, married. Thirteen years' diversified experience in research, development, production in impregnated diamond tools, synthetic sapphire, cemented carbides, iron powder metallurgy, desires responsible position with progressive and aggressive organization preferably in diamond tool or in high temperature metal-ceramic field. M-401.

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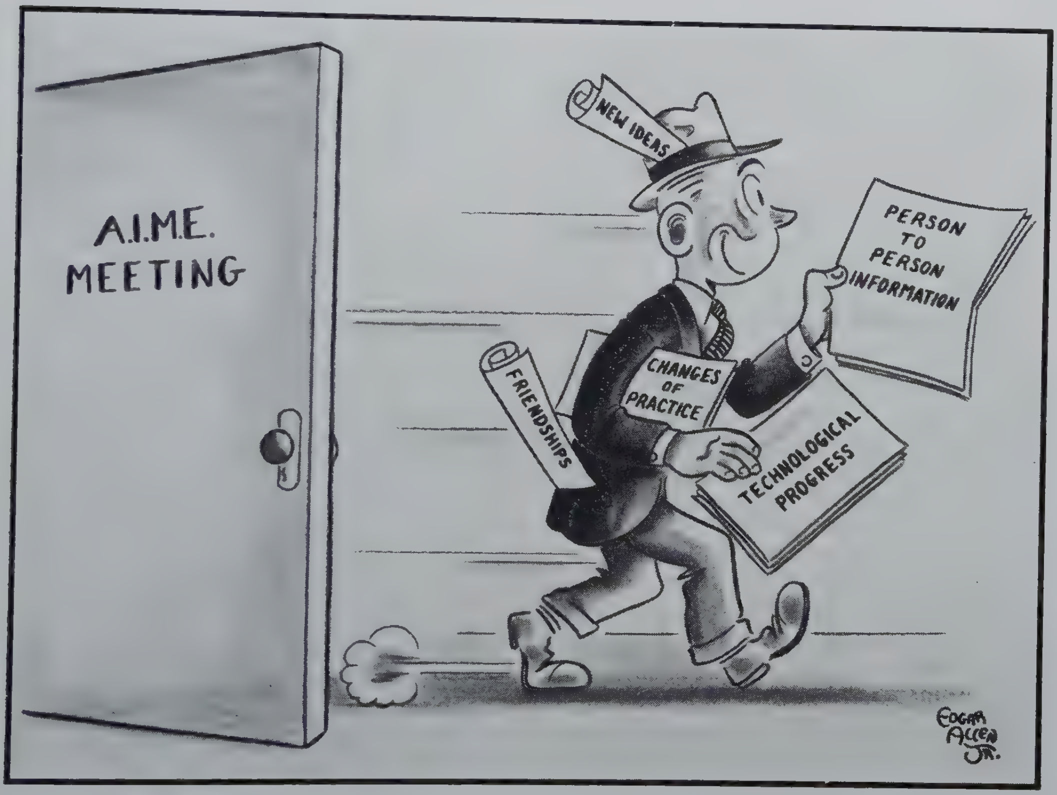


Getting Your Money's Worth

By **E. H. ROSE** • TENNESSEE COAL, IRON, AND RAILROAD CO., MEMBER, AIME

From the more distant members and some not so distant, the plaint is often heard that they cannot justify the expense and time required to attend the AIME Annual Meeting. Almost invariably, the reason given takes this form: "I just don't see that I would get enough out of it." Often the would-be clincher is added: "Besides, the meat of it all comes out in print anyway."

Not long ago, a group of us who have seldom missed a meeting in recent years fell to discussing this phenomenon, and found ourselves in emphatic agreement that anyone holding such a belief indicates by his first remark that he does not know how to attend a convention, and by his second, proves it. He is, by and large, the man who has never been there, and of him, there are many. Since he must often justify an expense account, these remarks are addressed to his employer as well, with the behest that prospecting for new technological knowledge or advances is like prospecting for ore or oil: the reconnaissance crews have to get out and look methodically, and in the right places, which are not necessarily the "obvious" places.

This observer does not profess to be an expert in the matter, nor even a good journeyman instructor, but some compelling points may be ticked off by anyone who has had repeated exposure to the atmosphere of mining meetings.

(1) *Information picked up in person-to-person contacts bulks far larger in take-home payoff than the official fare.* The formal presentations necessarily are contributions to knowledge in the broad sense. They deal with the contributor's experience, not the listener's. They are a one-way conversation, so to speak. The listener takes no really active part, other than discussion from the floor and that only after the speaker has had his uninterrupted say. There is no give and take concurrent with the presentation, and afterward it is too late for the knocking about of points of detail, even if time permitted, which it never does, and even if the listeners did not self-consciously "freeze" as they attempt their remarks from the floor, which many of them do.

But in the corridors, it's different. There and in the uninhibited informality of private rooms, where kindred spirits foregather, you find the source of the kind of information you came to get—the details too small or specialized to come out in the necessarily condensed formal sessions, the latest on-the-scene accounts of experiments known to be in progress but not yet advanced enough for formal reporting, the stories of experiments that failed and hence were not published to warn others away from the same blind alley, and the innumerable straws in the wind to indicate the direction of technological progress to come. There you do not take larger topics, one at a time, and exhaust them before passing on to the next. There you really get down to cases. I tell you how I am trying to do something; you come right back and tell me how you learned to do it better and you make me a sketch. You have heard that the Doakes mill has recently done itself some good by a change of flowsheet; I have recently visited that mill and tell you about it, since it is not confidential, and a Doakes man would tell you himself if he happened to be about. I have heard that the Hoozit Manufacturing Company has recently come out with a new automatic control device; you tell me you have had one in your plant for several months and it's a honey. You have heard that my outfit is doing some work with this new method of roof pinning; that happens to be off my beat but I take you around and introduce you to a man who knows all about it, whereupon the cycle begins all over again.

Little stuff perhaps, but of good assay, and sometimes a real nugget turns up. If our friend in the first paragraph insists upon measuring dollars to the disregard of satisfactions, he might calculate that one little such item reduced to practice back home for a saving of a picayune twenty dollars a month would pay for his annual trip to the meeting, even if he came from the other side of the continent. The "regulars" know that Lloyd's would make a neat profit by writing insurance to that general effect. It is, indeed, the reason those fellows show up year after year—without insurance other than their own convictions built up out of experience.

Nor is it all little stuff. I can cite chapter and verse on two major changes of practice in large plants that came about five years sooner than they otherwise would have, as the result of just such conversations in the byways of Annual Meetings—and no confidence violated in the process. Indeed, it was discovered afterward that the basic data and interpretation pointing the way to one of them had been published as an AIME paper years before, without the potential beneficiaries reading themselves into the act.

(2) *Repeated attendance pays increasing dividends.* Implicit in the foregoing is acquaintance with those persons of the most relevant interests, and the degree of mutual benefit is measurable by the degree of mutual friendship, understanding, and respect. The standoffishness of strangers is fatal; the camaraderie of old friends, perhaps not seen since the preceding meeting, is the instantaneous catalyst that induces the real reaction of minds, and the real yield of profitable guidance on both sides. It is no accident that the mining profession is unique in being commonly referred to as the "mining fraternity" and every meeting attests the aptness of that designation. He would be a backward soul, indeed, who, after the first year or two, could come away from any Annual Meeting without at least a dozen new first-name friends, to push his circle of provincialism correspondingly outward. (It is superfluous to ask if our Doubting Thomas averages a dozen new friends a year in his field by any other means open to him, unless it be by endless travel.) Attending regularly, his contacts, instead of becoming so broad he cannot cope with them, become the more selective and fruitful. An enlightening illustration came out of the 1947 Denver Regional Meeting, when Jack Myers and I exchanged our company reports on that gathering. As Jack put it, "You wouldn't think we had been at the same meeting," for the problems and points we discussed with others were not the same problems and points, because the operations of our respective personal concern and our sources were not the same, and likewise the gleanings we deemed most worthy of reporting to our respective managements.

(3) *Reciprocity is essential.* In addition to attendance, participation in Institute activities is the key that opens the door to the benefits sought. On that point, I can speak with authority, having been an Institute member for twelve years before attending my first meeting and sixteen before serving on a committee, but thereafter diving in enthusiastically. I can correspondingly understand the mental colic of the mail-order-minded member who sends in his annual dues and expects merchandise of said value to return to him at stated intervals. The poor fellow has his frustrations coming to him, but little sympathy. He's the chap who bought a bicycle but never learned to ride it, then complains that it doesn't take him anywhere. He has never really appraised the three points made herein, or if he has appraised them, has done so

under the handicap of not recognizing the Golden Rule, in professional society affairs, as not a rule at all but an automatic proportionality, truly though tritely expressed as, "You get out what you put in." The principle is that of trade; it is as simple as that.

Many inactive members sincerely believe that they are not qualified to write papers, for lack of either material or talent. Often, that may, indeed, be true, but it does not follow that they are unqualified to pursue other activities, such as serving on national or Local Section committees, all of which is as voluntary as the writing of papers and even more rewarding. Someone may say that he has never been "put" on a committee. The process is not quite so passive; one has first to open his eyes to the many ways in which he could be useful to others and thus in due process to himself and to his employer. To be selected, he must become visible. A few thoughtful letters written to the chairmen of committees covering his field of work or his geographic area—making suggestions, offering criticisms, or even merely asking the questions he asks himself verbally—and he will soon find himself out on the main line moving with traffic. He can be perfectly selfish about it, not for a moment pretending that such activity on his part is out of the kindness of his heart or for love of his fellow man, but strictly on the basis that such is directly or indirectly a sound currency of trade for any of the several desirable objectives: professional recognition, technological information, a promotion, or a different job. It just happens to work that way, as many can attest. Even on a committee, there will be no one standing at his elbow telling him what to do. It is his in-time-well-rewarded job to think of something to do, just as in the conversations stressed under point (1) he must contribute information as well as seek it.

And so, the question "how to attend an AIME meeting" or even "how to be an AIME member" boils down to one simple principle: "Give and ye shall receive." The mechanics of doing so presume a smattering of originality and extraversion, but beyond that one could more simply convey the idea by defining how *not* to attend an AIME meeting: don't just sit still and wait for the manna to rain down. You will be disappointed if you do.

Engineering Societies Library Reports

Library costs have risen more than Library income but not as much as the cost of living. The net result of this is that the Library can purchase relatively fewer books and magazines, and the staff has relatively lower income. By placing greater emphasis on paid services and by increasing the rates for services, the percentage of income from services has been doubled since 1939.

Pending funds from the Engineering Foundation, a survey to reorient the ESL with other technological libraries in the country is to be made. It is also planned to try to obtain support from industry.

Use of the Library has leveled off this year after a spurt in the two preceding years that had raised Library use more than 20 per cent. The statistics of Library use are:

	1946-47	1947-48
Visitors served	23,557	22,228
Nonvisitors served	17,098	17,442
Total	40,655	39,670
Photostat orders	4,392	4,135
Photostat prints	53,597	49,954
Microfilm orders	114	141
Searches	140	141
Translations	45	49
Words translated	136,192	212,288
Borrowers	1,835	2,200
Books loaned	2,628	3,011
Telephone inquiries	7,358	7,263
Letters written (exclusive of book orders)	3,214	3,513

A series of bibliographies has been initiated. These are intended for general distribution and they will be sold at prices that will at least cover their cost. The first is entitled "Filing Systems for Engineering Offices." Others in the series will cover various engineering topics of current and general interest in all fields of engineering.

Some persons who come to the Library have little or no knowledge of English but current members of the ESL staff can converse fluently with these persons in French, German, or Russian and with some difficulty in six other languages. Among the translators that are subject to call are persons who can translate almost any foreign language into English.

As in the past, the Library has received many valuable gifts of books and magazines. There were no outstanding gifts during the year, but some of the larger and more useful ones were those from the following: D. W. Barron, A. Eckwall, S. W. Farnsworth, M. Pirnie, B. W. Shaffer, and F. T. Sisco. Various technical societies, publishers, and other organizations have given generously of their own publications and other publications that have come to them. The Library has been enriched by the many gifts received. Sincere thanks are extended to all donors. It now contains 166,470 volumes, 10,514 maps, and 5056 searches, a total of 182,040 items. —*Ralph H. Phelps, Director.*

Pittsburgh Off-the-Record Meeting

Under the direction of R. F. Miller, of Carnegie-Illinois Steel Corp., and G. R. Fitterer, University of Pittsburgh, a most interesting program was arranged for the Nov. 12 all-day meeting of the Pittsburgh Section. It was attended by approximately 680 persons, of which 135 were students representing the University of Pittsburgh, Carnegie Institute of Technology, University of West Virginia, and Pennsylvania State College. Since the program was off the record, no attempt was made to make notes of the remarks of the individual discussers, but each session was interesting and educational, with good discussion of the papers. The National Open Hearth Committee held the largest number of sessions but the Coal Division, Institute of Metals, and Petroleum Division also held important meetings.

The meeting was concluded with a cocktail party through the courtesy of the suppliers' group of the Pittsburgh area under the chairmanship of R. S. Runyon and a dinner at which J. E. Thornton, special agent in charge of the Pittsburgh Office of the FBI, gave an interesting talk on his personal experiences as an FBI agent.—*Hugo E. Johnson.*

LEWIS EMANUEL YOUNG

President, AIME, 1949

Lewis E. Young, who will formally assume his duties as President of the AIME at the Annual Meeting in San Francisco in February 1949, was born in Topeka, Kansas, Oct. 1, 1878. Dr. Young received his engineering education at the Pennsylvania State College, where he received the degree of B.S. in Mining Engineering in 1900. In 1904 he received his E.M. degree from Iowa State College, and in 1915 a Ph.D. from the University of Illinois. In 1947, the University of Missouri conferred on Dr. Young *honoris causa* the degree of Doctor of Engineering.

His active career began in the educational field as instructor at Iowa State College, and following that, as professor of mining at the Colorado School of Mines, 1903-1907. While he was at Golden he launched his career as consulting mining engineer for various Western companies.

Leaving the Colorado School of Mines, Dr. Young returned to Missouri, serving the University of Missouri as director of the School of Mines and Metallurgy at Rolla, 1907-1914. Leaving Missouri he went to the University of Illinois as assistant professor of business organization, 1915-1918, during which period he wrote exhaustive treatises on mine subsidence and mine taxation, which won for him the degree of Ph.D. before mentioned.

With World War I confronting the nation, Dr. Young plunged into production work, becoming manager of the steam heating department of the Union Electric Co., of St. Louis, 1918-1922. With the completion of the Company's steam heating expansion program, Union Electric called on Dr. Young to fill the position of general manager of the Union Colliery Co., a wholly-owned subsidiary, where, for four years, 1922-1926, he pursued a program of complete mechanization of the Colliery Company's Kathleen mine, in Jackson County, Illinois.

With that task behind him, Dr. Young was offered the vice-presidency of the Pittsburgh Coal Co., which, subsequently combined with Consolidation Coal Co. and a number of lesser properties, became the Pittsburgh Consolidation Coal Co., the largest producer of bituminous coal in the world.

Dr. Young, never static, after resigning from the Pittsburgh Coal Co. in 1939, decided to go on his own, opening an office in the Oliver Building, Pittsburgh. Since then he has roamed, not only the United States, but in addition, Canada, the British Isles, France, Germany, and more recently South America, aiding and encouraging his many clients in the development of coal and nonferrous mineral properties, giving particular attention to mechanization, preparation, and cost reduction. Those who know Dr. Young best do not hesitate to say that his knowledge of mechanical mining methods is on a par with that of the top men in that field.

Dynamic in movement and speech, our friend will go anywhere, by air, land, or sea. Those who have followed the tall, rangy, one-time prof below the surface, in thin and steeply pitching seams, wonder how he keeps up his speed. No one would ever guess his age as seventy. Nowhere is he so happy as when addressing a body of young engineers, who invariably leave him with an added conception of the opportunities and responsibilities of the mining engineer. All over the United States, the one-time boys who sat in front of him in Penn State, Iowa State, Golden, Urbana, and Rolla, who are now mature men, invariably greet him effusively and affectionately, the conversation harking back to that most interesting of periods, their school days.

Through his busy career, Dr. Young has found time for writing numerous technical papers for this and other technical societies and engineering periodicals. Like practically all of the men who have achieved especial prominence in the mineral industry field, Dr. Young joined his professional society early—in 1901, the year after he graduated from Penn State. Elected a Director in 1937, he served three terms on the Board and was Vice-President from 1942 to 1945.

Dr. Young has one son, Edwin W. Young, engaged in newspaper work in the Middle West. Dr. and Mrs. Young make their home in Pittsburgh.—*E. M.*

Water, an industrial mineral, doesn't go to market in freight cars but moves in giant conduits. Here is a steel-reinforced concrete inverted siphon, 16 ft in diameter.

Water—

Industrialization is raising the standard of living of people everywhere. The common man is demanding and getting more of everything. Perhaps more markedly than most other things, he is consuming more water. A hundred years ago water for domestic use, in all but a few large centers, was lugged from wells in buckets. This still is true in many rural areas, even in the enlightened United States of America, but pumps and pressure systems are rapidly replacing the "old oaken bucket," even on farms and in isolated country homes. Nevertheless, many still fail to see water as a "commodity," in the same sense that coal, lumber, fertilizer, and bread are considered as commodities. Water is too frequently taken for granted.

If a mining man needs more air for a shaft or adit, he simply installs another blower and takes it from the conveniently adjacent atmosphere. The industrialist, needing more air for a factory or building, does the same thing. The availability of an inexhaustible supply of air for such uses is fortunate. It also would be fortunate if other elements essential to human activities were equally available, but, of course, they are not. Food, clothing,

Transporting water by canal is one way to get it there. There are 63 miles of concrete-lined open canals in the 242-mile main aqueduct system which carries water from Lake Havasu to three million inhabitants of Southern California.

A paper presented before the Industrial Minerals Division, AIME, at the Oct. 24 meeting in Los Angeles.

Lowest Cost Industrial Mineral

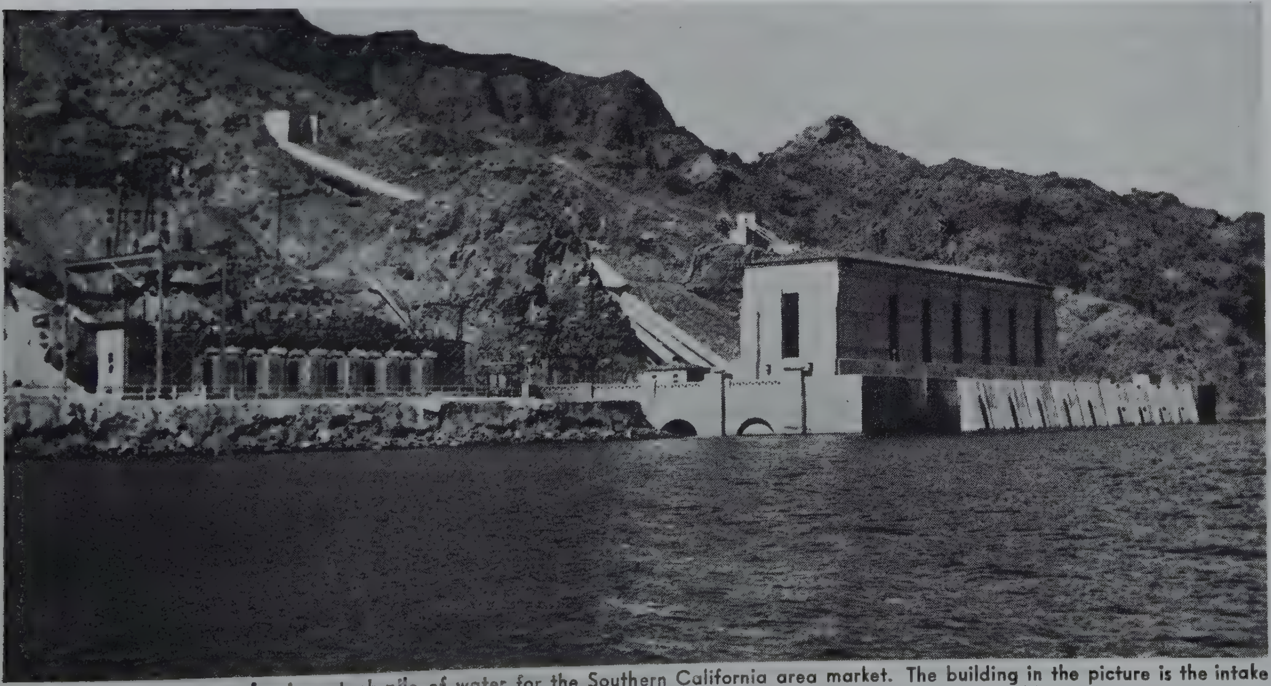
By **JULIAN HINDS** • GENERAL MANAGER, METROPOLITAN WATER DISTRICT, LOS ANGELES

shelter, and the thousand and one things required to meet modern needs are obtainable only at the expense of exertion.

There was a time when water for most people and for most purposes was almost as abundant as air. Our not too distant ancestors, thinly scattered over humid areas or grouped in small numbers about oases, gave little thought to water as a problem—except in times of unusual drought. If more water was needed, another bucket was sent to the spring or stream, or another shallow well was dug. Increasing numbers and the spreading of populations into arid regions have changed this. Water has become one of the elements that must be striven for.

This change has come about so gradually that the average man on the street is not too painfully aware of it. The city dweller thinks of water as something that comes out of faucets. If he wants more water, he buys another faucet, little aware of the effort often required to find the water, refine it, and pipe it to his outlet. Ordinarily, this is as it should be. Production is left to experts, just as the production of coal or copper is left to the expert miner and metallurgist.

At times, however, the consumer needs to give serious thought to the nature and adequacy of the source of his



Lake Havasu reservoir is a stock pile of water for the Southern California area market. The building in the picture is the intake pumping station which starts the water on its way over the longest man-made aqueduct system in the world.

Hoover Dam, keystone of the Colorado River aqueduct development program, measures 727 ft from foundation to crest.

water. This applies to the home owner as well as the miner about to open a milling plant in an arid region. It applies particularly to those proposing to initiate water-consuming industrial enterprises.

Unfortunately, water is all too frequently the last thing a promoter thinks of. This was particularly true during the war. Factories and housing projects were built with great abandon on flat spots that could be bought cheaply, only to discover too late that the site was cheap because it had no water.

The same thing can happen in peacetime. As a recent example, the promoter of a postwar cement project in southern California acquired suitable deposits in the desert, arranged for a power supply, expended great effort locating the required machinery, and was about ready to start construction before investigating the water supply. There was none. Mining ventures likewise have been developed and abandoned because of inadequacy of water supply—a condition which should have been foreseen. The same careful advance consideration should be given to water as is given to power, raw materials, and other essentials.

The water system built along the Colorado River aqueduct of the Metropolitan Water District, to supply water for construction purposes, affords a good example of water planning for a specific enterprise. This great waterway was to be built 250 miles across a desert, devoid for much of this distance of any visible water for the maintenance of life or for construction purposes. Careful reconnaissance indicated the possible presence of underground bodies of water in rather widely separated desert basins; many were salty, but usable supplies were found at forty- to fifty-mile intervals. Obviously, it would have been uneconomical to require each individual contractor to transport water over such distances. Consequently, as a preconstruction enterprise, the District developed all of these sources, provided pumps and storage reservoirs, and laid a construction water line for the full length of the project. Fifteen usable wells, varying from 16 to 785 ft in depth, were drilled in half a dozen locations. There were also a number of salt wells and "dusters." The supply line consisted of 180 miles of 5-, 6-, and 8-in. diameter lightweight, continuously-welded steel pipe, laid in shallow trenches. The total cost of the system was $847,000 and it was much more than worth it. The supply was adequate.

Such elaborate planning of a water supply for an individual project is, of course, unusual. Most large enterprises can tap some community water system. Before risking any great investment, however, both source of supply and adequacy of delivery system should be investigated.

Most water-supply systems have grown more or less piecemeal, starting with a few families and expanding by various expedients with the growing population, systematic planning being introduced at some later date to avoid an impending disaster. In this way, the great modern water developments of the world have grown.

A most interesting example is found in the development of water in southern California. The white man found this an arid region, an excellent place for a few people to live, but subject to severe and prolonged droughts. During wet periods there were lush pastures, springs, and flowing streams, encouraging increased development, expansion of herds, and the introduction of irrigation. Then came drought. Irrigation ditches ran dry, cattle died, and people moved away. But in spite of these periods of discouragement, there was some permanent development. The climate was good, soil fertile, and all kinds of fruits and crops flourished wherever and whenever there was water.

Ground water as a source of irrigation supply was not at first taken seriously, but wells were, of course, resorted to for domestic supplies, and at times of drought for watering livestock and perhaps for home gardens. The early dug wells merely tapped shallow surface sources, but finally, with the introduction of the drilled well, someone pierced the clay cap and struck a gusher—a bountiful artesian flow. The boom was on! Here were vast expanses of wonderfully fertile lands, with a bountiful water supply just a few hundred dollars beneath the surface. Development went forward at a stupendous rate. Nobody asked where the water came from, how much there was, or how long it would last. There was no organization to ask such questions and the individual farmer was too busy to ask anything. The supply was looked upon as inexhaustible, and wells multiplied.

Soon outflow began to exceed replenishment. Pressures dropped and wells ceased to flow. But the farmers. now grown wealthy, were loath to walk off and leave their homesteads. Furthermore, they could now afford to pay for water—they could afford to pump it. And so pumps went down as fast as artesian flows stopped. And more pumping wells were drilled, still with the feeling that there were great underground oceans of fresh water, to all intents and purposes inexhaustible. And thus began one of the most stupendous mining operations of all time.

As geologists later explained, there actually was a vast, though not inexhaustible, underground storehouse of water. Practically the entire coastal basin is deeply underlain with porous detrital fills, covered with a blanket of topsoil and clay of varying thickness. Each year a small portion of the sparse rainfall and meager mountain runoff around the upper perimeter of the basin sinks into the ground. During prehistoric ages these small percolations completely filled the underlying strata and welled up against the clay cap covering the lower portions, creating an artesian pressure. It was thus revealed that the early settler's herds had died of thirst on the roof of an enormous lake of good water.

But it was only a lake and not an inexhaustible sea of fresh water, as many wishfully believed. With increased pumping, water levels sank and many wells went dry, or lowered levels permitted sea water to flow landward, contaminating the source of supply. Ultimate exhaustion became obvious, but abandonment was by now out of the question. Experts were employed and the problem was studied from all its angles. Steps were taken looking toward complete conservation of all flood waters formerly wasting into the ocean. Spreading works were constructed to encourage percolation into the underground basin, and surface storage was created where possible.

But these measures were inadequate. An annual rainfall of 15 in., no matter how thoroughly it is conserved, cannot support a semitropical civilization. Importation of water was obviously essential. There is no long river bringing water in naturally from distant sources, and near-by surrounding territory is true desert, producing no worth-while runoff. So, early in the present century it became evident that an artificial waterway to some distant point must be constructed. As a result, the then small City of Los Angeles voted the stupendous sum of $23,000,000 to build an aqueduct to tap the Owens River, 250 miles to the north. This river collects the drainage from the precipitous eastern slopes of Mt. Whitney and other snow-capped mountain peaks of the High Sierras.

Setting steel to reinforce concrete in a 16-ft high conduit.

The aqueduct was completed in 1913 with a capacity of 450 cfs. It was expected to end the water needs of Los Angeles for all time. But just as the discovery of artesian flow engendered overdevelopment, so did the introduction of Owens River water. The inexhaustible idea was again rampant, and the city began doubling in population every ten years. Leaders soon saw that the battle for water had just begun and eyes were turned to the only other adequate source—the Colorado River—frequently referred to as "the last water hole of the Southwest."

Water from the Colorado River for the coastal areas of southern California could be obtained only from the flood flows. Normal low flows were already completely appropriated. The creation of storage on the main river was not a job for a single community. The stream is interstate (in fact, international), floods are great, and silt is a problem. The political situation was complex. But the problem was courageously attacked and solved.

The amount of work involved has been prodigious. Interstate compacts, enabling acts in Sacramento and Washington, and contracts and agreements on a national scale consumed unimaginable time and effort. Finally. construction of Hoover Dam by the U. S. Bureau of Reclamation was authorized. The Metropolitan Water District, comprising the principal cities of the South Coastal Plain, was organized, and $220,000,000 worth of bonds was voted to build an aqueduct to bring more than one million acre feet per year of the conserved water to the needy coastal communities. The job was started in the bottom of the depression and finished just before the beginning of the war, substantially under the original estimate of cost.

This aqueduct again was expected permanently to end the water worries of southern California. It is now evident that this is not the case. The necessity for some

Barring down after the blast which holed through the San Jacinto tunnel. This tunnel pierced 13.04 miles of solid rock in the San Jacinto mountain range and was the most difficult unit of the entire metropolitan aqueduct construction.

limitation of ultimate development is likely unless an additional source beyond "the last water hole" is found and tapped.

This story illustrates the effort involved in planning for a water supply. Most systems are, of course, smaller and simpler. Many of them have been planned with relatively as much care as that described, but usually with less elaborateness. Many small municipal and private systems are still going largely on faith and although usually adequate for ordinary needs, cannot stand a sudden expansion of demand. A prospective investor should carefully check the adequacy of such supplies.

Reference has been made to the extraction of ground waters in the southern California coastal area as a mining operation. Water being a mineral, this reference is perhaps justified by the dictionary definition of mining. The primary distinction between water mining and the mining of other minerals is that water is sometimes replenished by percolating rainfall, permitting the continued repetition of the mining operation. In the Los Angeles coastal area this was only partly true. In fact, the foundation of the present great civilization in this region was built on fossil waters, accumulated through countless prehistoric ages. These basins never again will be fully filled, and the "take" must now be limited to the annual crop. Nevertheless, the beneficial effect of the fossil waters was great. The artesian wells produced the wealth that could afford to pump; the pumped wells produced the wealth that could afford to build the Owens River aqueduct; and the supply from this source produced the wealth required to go to the Colorado River. If any of these links had been missing, the chain could not have been forged.

Production of water by mining operations is, of course, not limited to southern California. Well waters are used throughout the world for individual supplies, municipal supplies, and irrigation. Production is often deliberately undertaken on a pure mining basis, with no hope or expectation of replenishment. Desert lands underlain by nonreplenishing water bodies have been hurriedly put into cotton or other temporarily high-priced crops, with the hope of a quick return, and with the expectations of abandonment after a few years, but such operations are likely to be detrimental to adjacent lands depending on a perennial underground water crop.

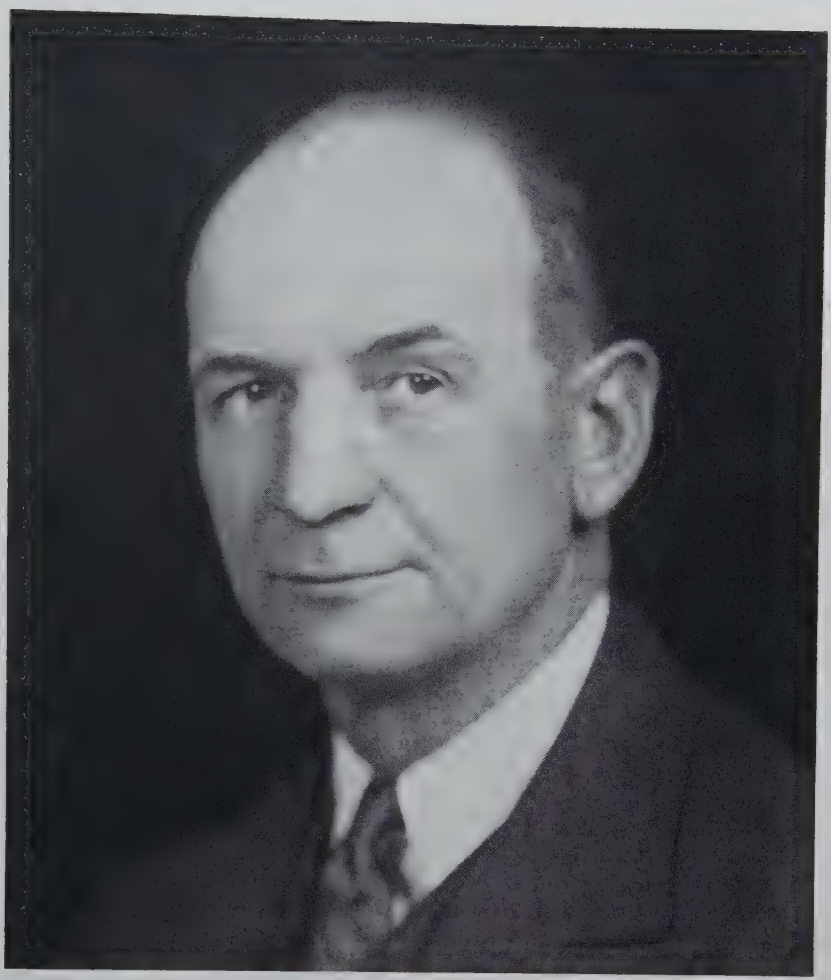
Water, like other mineral products, must be transported to its points of use after it is "mined." Sometimes it also must be refined—that is, softened or otherwise purified. In contrast to most commodities, water is delivered right where it is wanted, as wanted. It is not necessary to go to the railway station, warehouse, or store, and haul it home; or to wheelbarrow it in from the front yard. Its delivery is complete and the price of delivery is ridiculously low.

When the Colorado River aqueduct shall have reached full development, it will be capable of transporting 1 2/3 billion tons of water per year from 300 to 400 miles, lifting it through a height of over 1600 ft, and delivering it wholesale into the water systems of the coastal area at a cost slightly over one cent per ton, including interest on investment, depreciation, power for pumping, and all operation and maintenance costs. Refining (softening and filtration) will add another half cent per ton to the wholesale price. The retail price of water for household use in southern California will average about five cents a ton, delivered into the sink or bathtub, as and when needed. Irrigation and industrial water is much cheaper.

Thus the water producer sets a standard of economy which other producers and shippers will find it hard to approach—not because the water man's problems are easier, but because conditions favor low-cost production and because the volumes handled are so enormous.

JOHN FLICKINGER MYERS

Chairman, Minerals Beneficiation Division, AIME



In Emporia or Claremore, time was when a path was beaten to the door of the local sage. Nowadays, the beginnings of such a path are discernible in Tennessee, as folks of the metallurgical persuasion find it to their pleasure and profit to call upon the Sage of Copperhill. They come, more and more respectfully as the years go by, yet to ever fewer persons is he known as Mr. Myers, but to more, eloquently, as Jack. Find better ways to run your mill, find happier means of co-ordinating your humanities or serving your professional society, and it's just like the man said about the mousetrap.

A druggist's son, born in Wisconsin, May 24, 1889, reared on the Bible in Ohio and Indiana, and completing his education in Colorado, this now indisputably 24-carat Tennesseean has had a checkered career. Going West as a laborer at the tail end of the 1907 panic, he did not make his fortune but he did gain an understanding of labor that in later years endeared him to his men. Graduating in 1913 from Colorado School of Mines with the degree of E. Met. and a string of football letters (also earned the hard way, at tackle) he went to work in Butte & Superior, just at the beginning of the Golden Age of flotation.

A year later, Jack is starting up the flotation plant of American Zinc at Mascot, Tenn., and putting an item into the textbooks, to wit, that copper sulphate is vital to the flotation of zinc sulphides. A year after that, now with New Jersey Zinc at Austinville and Canon City, he rounds out this discovery with first-order pioneering in alkaline circuits, and a patent or two. It was in 1926 that he joined Tennessee Copper to begin a dogged uphill fight to attain the frankly unattainable, such as a premium iron sinter from a three-metal *sulphide* ore, meaning a sinter containing less than 0.10 per cent copper or zinc. That takes some doing.

In a small operation in a little town, Jack has won international recognition. The credit he gives to others, with such compelling plausibility that maybe we shouldn't go into that. First, there's Billie, the girl he met in Butte, married in 1915, and has stayed married to ever since. Whatever their other doubts, those who know Billie concede that Jack showed early intelligence. (They have one son, Lorrin, who is now bouncing upward in NBC in a curiously reminiscent pattern.) Second, there's the AIME. Jack says—and so help me, he can prove it!—"Ninety per cent of our success here has come from AIME contacts. Sometimes I am ashamed of how little we ourselves have done and how much other folks have helped us."

We can't rightly say how much of that last is accuracy and how much is modesty, but whatever the ratio they add up to a humility the rest of us could do with a lot more of.—*E. H. R.*

THE DRIFT OF THINGS

. . . as followed by **EDWARD H. ROBIE**

A Fourth Round?

Talk is increasing about another round of wage increases—the fourth round. True, the cost of living has risen by some 7 per cent during the last year, so on this basis some further wage increase can be considered justified. But the rising cost of living shows some signs of tapering off; in fact, for the last month reported, it did drop off by a fraction of a point, the first time this has occurred. If this means that the advance has been stopped, then it is to be hoped that further wage increases can be held in abeyance, for experience has established the fact that a national round of wage increases causes a rise in the cost of purchased goods and services in an equal or even greater dollar amount than the increase in employment costs. However, the labor unions argue that, in the words of Gershwin's song, this "ain't necessarily so"—that the increase should come out of swollen profits.

Mr. Holman on Petroleum Trends

One product of the mineral industry that seems to be in increasing demand every year is petroleum. Even the excessive wartime demand was exceeded in the first year after hostilities ceased and the consumption has set new records every year since. Unlike many of the metals, however, petroleum has always been found in peacetime in sufficient quantity to meet all demands. As to the future, some have questioned whether we can count on the necessary increase in United States output or imports, and feel that some reliance will have to be placed on synthetic production from natural gas, oil shale, or coal.

In a talk before the Texas Mid-Continent Oil and Gas Association recently, Eugene Holman suggested that we could not count on the Middle East for a part of our oil except as a temporary measure, adducing two main reasons: first, Europe will soon be able to absorb all of the Middle Eastern production, when the necessary refineries are built; and second, for American capital, the cost and risk of development so far away are too high and the distance to market in this country too far, with import duties also to be paid.

One way that Mr. Holman thinks the problem of balanced supply and demand can be met is by improving the efficiency of oil-consuming equipment. He cites the Diesel locomotive as the outstanding example at present, for it will do the work of the oil-fired steam locomotive with about one fifth of the oil. Also, we may look for greatly increased automobile engine efficiency, and as gasoline for motor vehicles accounts for some 41 per cent of our petroleum consumption, any appreciable increase in efficiency here means much. Another economy will be found in the increasing ability of refineries to make gasoline and Diesel oil out of residual oil that was formerly burned, which can be displaced by coal, natural gas, or imported residual fuel. Presumably, therefore, fuel oil may become relatively more expensive than gasoline or Diesel fuel.

Annual Reports

Each year recently we have noted an increased tendency for mining companies, particularly those that have a product to sell to the general public, to issue fancy annual reports, printed in several colors on slick paper with plenty of photographs and art work. These are nice to look at but whether or not the companies get their money's worth out of them is questionable. Is this fancy presentation what the stockholders want?

Elmo Roper, while his reputation was still good, recently conducted an exhaustive survey for the Controllership Foundation (1 E. 42d St., New York City 17) which has published his findings in a pamphlet under the title "What People Want to Know About Your Company." It discloses that the average stockholder has little interest in corporate financial data, and uses other means of keeping track of his investment and deciding when to buy or sell. Some forty per cent of "run-of-mine" stockholders said they found no utility in the annual brochures they received. They want to know what the chances are that the company will safeguard its capital and pay the same or bigger dividends and they would appreciate a little discussion along this line. Only big investors want financial details, and they want much more than is given in the usual report.

So the Foundation recommends a brief statement, to go to all stockholders, outlining earnings, dividends, and the general financial position and outlook of the company, and offering a complete report on request. The latter would be a full-scale annual report designed primarily as a source document for those who wish ready access to cold statistical facts. Employees would also like the brief digest.

The above applies to companies in general—not specifically to mining, metallurgical, or oil companies. For companies in the mineral industries field, we think AIME members would like to read in addition a statement every year (maybe 2000 words for the big companies, ranging down to a few hundred for the smaller companies) outlining the properties worked, new methods and equipment used, ore reserves, grades, recoveries, costs so far as can be divulged, results of exploration and development, new products and markets, labor conditions, names of operating officials, and a few other data of this general nature. But stockholders would not be so much interested as professional men, so we suggest that a brief annual report giving this information be offered for publication in the journals serving the industry.

News From the AEC

Not a great deal of news regarding its raw material supply emanates from the Atomic Energy Commission, but there seems no reason to doubt that most of the domestic supply of uranium ore continues to come from western Colorado, with that area also affording most promise for the future. Thus one of the oldest settled areas of the country, which was inhabited fifteen hundred years or more ago by the cliff dwellers, affords the newest of man's vital minerals. Within the last two or three months, arrangements have been made to facilitate the treatment of uranium ores offered by the individual prospector and operator. The U. S. Vanadium Corp. (Carbide and Carbon subsidiary) has agreed to purchase from independent miners, for treatment at its plant at Rifle, Colo., 63 miles northeast of Grand Junction, any ores adaptable to the process used there. Formerly, only company ore was treated. This will afford a market for ore mined in the northern part of the Colorado plateau and eastern Utah, and it is thought the plant may now operate at twice the scale that it has heretofore.

Another item of news has to do with southwestern Colorado, where the Vanadium Corporation of America is to take over and rehabilitate, at a cost of some $200,000, the vanadium-uranium mill owned by the Atomic Energy Commission at Durango, and formerly owned by the U. S. Vanadium Corp. Some of the ore supply for this mill, which is expected to go into operation later this year, will come from Navajo Indian lands, for which the Indians will receive a royalty. As at the Rifle plant, ore will be received from independent miners.

Vanadium Corporation also plans to erect a pilot plant in the White Canyon district of San Juan County, Utah, which heretofore has not been a producer but which has small, flat lenticular deposits of copper-uranium minerals. The mineralization extends across the line into Arizona, and prospecting should be stimulated.

These plants should do much to dissipate the dissatisfaction that many independent operators have voiced in the past concerning a satisfactory market for their product. The price they will get, however, is not a matter of bargaining between the miner and smelter, as for base-metal ores: it is set by the AEC, presumably at a level which they think will provide a reasonably adequate supply.

Many inquiries are also reported by the AEC regarding the possible value of thorium as raw material for nuclear fission. Monazite ore is the principal source of thorium, but there is little encouragement at present for producers of that mineral. Uranium 233 can be derived from thorium in a way similar to that in which plutonium is derived from uranium, and uranium 233, of course, is a desired fissionable material. However, complex research problems remain to be solved for the large-scale utilization of thorium in this way. Maybe in ten years or so monazite will be a raw material for nuclear energy, but not now. But until then, it remains the only known source of cerium and some other rare-earth metals which have varied, even though not extensive, uses.

And monzonite, if some prospector asks, is as worthless as ever.

Then and Now

When we were a little boy the first real engineering job that we had assigned to us was the operation of a small wood-fired boiler supplying steam to a pump that forced water uphill to a tank a few hundred yards away for irrigation in an orange grove. Our principal job was to keep the steam pressure up to at least 60 lb and to whistle for help when the water got near the bottom of the gage glass, for we were not quite equal to manipulating the injector or "inspirator" as it was called. Occasionally a bad and bigger boy would scare the daylights out of us by coming around, tying the safety valve down, and running the steam pressure up to about 90 lb, which we thought likely to blow the whole place, including us, to smithereens.

Our mind ran back to these early days when we read the other day of a new Westinghouse 100,000-kw turbine that runs at such a high temperature and pressure that the steam pipes feeding it glow a dull red. The steam is at 1500 lb pressure and at a temperature of 1050F. This is 50° higher than any temperature previously used in turbines. To operate in the dull-red region all high-pressure parts of the turbine were made of 18-8 stainless steel. Fabrication of parts from this hard-to-work material was difficult.

Each 50-deg. increase in the steam temperature means a saving of about 1.4 per cent in fuel. Back in 1915 steam turbines averaged only 525 kw-hr per ton of coal burned. By 1945 the figure was 1550 kw-hr as an average for all plants, old and modern, then in use. This new turbine will produce about 2500 kw-hr of electrical energy from each ton of coal burned.

We All Have Them

We suppose that readers of this journal expect its articles to be couched in good English, but sometimes when we have to rewrite articles written by foreign engineers whose knowledge of English is not too good, we run into expressions that we hate to change. For instance, one writer states in his manuscript that, in a certain foreign country, shortage of labor coupled with demand for increasing production "has made painly headache to the leader of the industry." Painly headaches are not unknown to the leaders of industry in the USA either, nor to editors and acting secretaries, it might be added.

Program, Annual Meeting, AIME, San Francisco, February 13-17, 1949

MBD, Minerals Beneficiation Division; MIED, Mineral Industry Education Division; SEG, Society of Economic Geologists; IMD, Institute of Metals Division; ISD, Iron and Steel Division; EMD, Extractive Metallurgy Division.

Sunday, February 13

2 p.m.—MBD (*Business Session*).
2:30 p.m.—MIED (*Mining and Metallurgy Forum*).
7 p.m.—MIED (*Petroleum, Geology, Geophysics Forum*).

Monday, February 14

8:30 a.m.—Registration.
9 to 9:30 a.m.—Meeting of presiding officers and authors of the day.
9:30 a.m.—Section Delegates.

9:45 a.m to 12 m.

Coal Division and MBD (*Preparation*).
Health and Safety in Mines.
Industrial Minerals Division.
MIED.
Institute of Metals Division.
Iron and Steel Division.

12:15 p.m.—All-Institute Luncheon.

2:30 p.m.

Section Delegates.
Mining Methods Committee.
MBD (*Grinding*).
Industrial Minerals Division (*Economics*).
Petroleum Division (*Production Review*).
Coal Division (*Preparation*).
Extractive Metallurgy (*Lead and Zinc*).
Institute of Metals Division.
Iron and Steel Division.

4 p.m.—Research Committee (*Annual Meeting*).
5 p.m.—Executive Committee, Coal Div.

Evening—Informal Dinner Dance.

Tuesday, February 15

8:30 to 9 a.m.—Meeting of presiding officers and authors of the day.

9 a.m. to 12 m.

Petroleum Division (*Economics*).
Coal Division (*Preparation*).
Mining Methods Committee.
Industrial Minerals Division.
MBD (*Flotation Practice*).
Mining Geology Committee and SEG.
IMD (session preceded by business meeting).
Extractive Metallurgy (*Lead and Zinc*).

9:45 a.m.—Woman's Auxiliary (*Annual Meeting*).

11 a.m.—IMD Annual Lecture.

12:15 p.m.—Luncheons

MIED. MBD. Coal Division.
Mining Geology Committee.
Metals Branch Luncheon.

2 p.m.

Executive Committee, ISD.
Annual Institute Business Meeting followed by meeting of Board.
Mineral Economics Committee.
Mining Methods Committee.
Mining Geology Committee and SEG.
MBD (*Flotation Theory*).
MBD and ISD (*Pyrolysis and Agglomeration*).
Coal Division.
Industrial Minerals Division.
Institute of Metals Division.

Evening

Petroleum Branch Dinner.
SEG Dinner.
Stag Party.

Wednesday, February 16

8:30 to 9 a.m.—Meeting of presiding officers and authors of the day.

9 a.m. to 12 m.

Petroleum Division (*Technology*).
Coal Division.
Mining Methods Committee and Industrial Minerals Division (*Phosphate Symposium*).
MBD (*Hydrometallurgy*).
Mining Geology and SEG.
Extractive Metallurgy (*Blast-furnace Charge Preparation and Dross Treatment*).
9 to 11 a.m.—Iron and Steel Division.
9 to 11 a.m.—Institute of Metals Division.

9:45 a.m.—Woman's Auxiliary (*Round Table*).

11 a.m.—Howe Memorial Lecture.

12:15 p.m.—Luncheons

Industrial Minerals Division.
Mining Methods Committee.
Executive Committee, IMD.
U. S. Section, PAIMEG.

2 p.m.

Petroleum Division (*Technology*).
Coal Division.
Mining Methods Committee.
Mining Geology and SEG (*Atomic Mineral Deposits*).
MBD (*Hydrometallurgy*).
MBD and Industrial Minerals Division.
Industrial Minerals Division.
Powder Metallurgy.
Institute of Metals Division.

Wednesday, 2 p.m. (continued)

Extractive Metallurgy (*Lead and Zinc*).

5 p.m.—Executive Committee, Industrial Minerals Division.

Evening

Annual Banquet and President's Reception.

Thursday, February 17

8:30 to 9 a.m.—Meeting of presiding officers and authors of the day.

9 a.m. to 12 m.

Mining Methods.
Geophysics.
MBD (*Gravity Separation*).
Extractive Metallurgy Division; Joint Session, EMB, Industrial Minerals, and Iron and Steel Divisions (*Titanium*).
Industrial Minerals Division.
Powder Metallurgy, IMD.
Executive Committee, Petroleum Division.

2 p.m.

Forum for Students.
Geophysics.
Powder Metallurgy, IMD.
MBD "Cleanup" Session.
Research Committee on Comminution.
Extractive Metallurgy (*Copper and Aluminum*).
SEG (*Geology of Ground Water*).
Executive Committee, Petroleum Division.

View of San Francisco, called Yerba Buena, before the discovery of gold in 1848.

Courtesy Wells Fargo Bank

Every Field of AIME Activity to Be Covered in Over Sixty Sessions at Annual Meeting in San Francisco Feb. 13-17

THE Institute's 1949 Annual Meeting—its 168th general meeting—will be held in San Francisco, Feb. 13-17. This is only the second annual meeting in recent years to be held outside New York City, and the first ever held on the Coast. Under the chairmanship of William Wallace Mein, Jr., plans are rapidly taking shape to make it an outstanding event. It is timed to coincide with the Centennial Celebration of the California gold rush. Entertainment will be in traditional San Francisco style, with a social program of more than usual interest. Mrs. H. Robinson Plate, Chairman, Northern California Section Woman's Auxiliary, promises the ladies a time to remember.

Technical sessions, numbering more than sixty, will be held by practically all Divisions and Technical Committees of the Institute and many group dinners and luncheons are scheduled.

Airplane flights covering points of cultural, industrial, mining, and geological interest are being scheduled for Feb. 15, 16, and 17. They will be courtesy of Pan American Airways. For details of the post-meeting tour to Hawaii see page 635, Nov. M&M. There is some talk of a winter trip to the Yosemite Valley.

Headquarters will be the Fairmont Hotel. Members who have not yet made arrangements should write for hotel reservations to AIME Housing Bureau, Room 200, 61 Grove St., San Francisco 2. Give a first and second choice of hotels, and enclose a deposit of $5 per person or $10 per room. Some informal get-togethers are scheduled for Sunday, Feb. 13, and registration starts Monday morning.

A fee of $3 will be charged members at time of registration; nonmembers, $5.

The Section Delegates meet Monday morning and afternoon. The Institute annual business meeting on Tuesday afternoon, to which all members are invited, will be followed by an executive session and a general meeting of the Board of Directors.

The welcoming luncheon for members, their ladies, and guests, will be at the Fairmont Hotel, Monday. Ticket, $3.75.

Dinner Dance, Monday evening. Ticket, $7.50.

Stag Dinner, Tuesday evening. Ticket, $10.

Institute Annual Banquet, Wednesday evening. Ticket, $10.

All reservations for functions should be made by mail to Mr. Worthen Bradley, Room 200, 61 Grove St., San Francisco, and be accompanied by check in full, payable to George H. Playter, Secretary-treasurer, San Francisco Section AIME. Tickets will be mailed for all reservations received up to Feb. 1. No advance reservations can be accepted except by mail.

Dinners—The annual Branch (IMD,

ISD, EMD) dinner and the annual dinner of the Petroleum Division (Petroleum Branch) will be on Tuesday evening. Same evening, annual dinner of the Society of Economic Geologists which is meeting at joint technical sessions with the Mining Geology Committee.

Luncheons — During the Annual Meeting these special luncheons will be held:

MONDAY

All-Institute Luncheon.

TUESDAY

Mining Geology Committee.

Coal Division.

Minerals Beneficiation Division.

Mineral Industry Education Division.

Metals Branch (IMD, ISD, EMD).

WEDNESDAY

Mining Methods Committee.

Industrial Minerals Division.

Executive Committee, Institute of Metals Division.

U. S. Section, PAIMEG.

The annual meeting committees are as follows (entire personnel will be given in final program):

William Wallace Mein, J. D. Mackenzie, Donald H. McLaughlin.

General Committee: Wm. Wallace Mein, Jr., chairman; Edward Wisser, vice-chairman; George H. Playter, secretary-treasurer.

Finance Committee: Walter L. Penick, chairman; W. C. Collyer, vice-chairman; Gilfry Ward, vice-chairman.

Entertainment and Hospitality Committee: Worthen Bradley, chairman; Granville S. Borden, vice-chairman.

Advisory and Reception Committee: Robert A. Kinzie, chairman.

Banquet Committee: Walter L. Penick, chairman; Worthen Bradley, vice-chairman.

Dinner-Dance Committee: P. R. Bradley, Jr., chairman.

Stag-Smoker Committee: Herbert A. Sawin, chairman; Granville S. Borden, vice-chairman.

"All-Institute" Luncheon Committee: George H. Playter, chairman.

Hotel Committee: W. W. Bradley, chairman: E. B. DeGolia, vice-chairman.

Publicity Committee: Lewis A. Parsons, chairman.

Education Committee: Carlton D. Hulin, Lester C. Uren, Edward Wisser, Bernard York.

Field Trip Committee: Gordon I. Gould, chairman.

Authors and Presiding Officers—Get-together after-breakfast meetings of presiding officers and authors will be held at 9 to 9:30 a.m., Monday, and 8:30 to 9 a.m., Tuesday, Wednesday, and Thursday. The meetings will be casual in nature—they will afford an opportunity for authors and chairmen to ask questions and for the Institute staff to impart pertinent detail on arrangements and facilities at specific sessions. The presiding officers' envelopes, containing the available papers, written discussion, etc., will be distributed to the chairmen of sessions at these meetings, and chairmen and authors will have opportunity to become acquainted.

Robert Gordon Sproul, president, University of California, will be the principal speaker at the Annual Banquet at the Palace Hotel on Wednesday night, at which honors will be conferred as follows:

Charles F. Rand Medal to Harry Carothers Wiess (posthumously) "for energy, wisdom, and administrative ability which found expression in major contributions to the economy of the nation and the world; for high courage and vision in services to the petroleum industry; for ceaseless efforts in fostering during World War II the production of strategic supplies; for a greatness of character which showed itself in his many philanthropies and in the respect of all who knew him."

William Lawrence Saunders Medal for distinguished achievement in mining to Stanly A. Easton "for his leadership and activities over a period of fifty years in the development of the Bunker Hill and Sullivan, one of the great mining enterprises of the world."

James Douglas Medal in recognition of distinguished achievement in nonferrous metallurgy to William Wraith "for conspicuous leadership in and fundamental contribution to technologic progress in the arts of beneficiating ores of nonferrous metals, especially those of copper."

Erskine Ramsay Medal in recognition of distinguished achievement in the production, beneficiation, or utilization of bituminous or anthracite coal to Eugene McAuliffe "for his leadership and initiative in the promotion and achievement of better safety, more efficiency, and improved working conditions in coal mining, which have led to a more healthful coal industry."

Robert W. Hunt Award to M. Tenenbaum for his paper entitled "Structure, Segregration, and Solidification of Semikilled Steel Ingots."

The Institute of Metals Division Annual Award will be presented to E. A. Gulbransen and J. W. Hickman (posthumously) for their paper entitled "Electron Diffraction Study of Oxide Films on Iron, Cobalt, Nickel, Copper and Chromium."

J. E. Johnson, Jr., Award to John Daniel Saussman for his paper entitled "Sinter Practice, Kaiser Company, Inc., Fontana, California."

Rossiter W. Raymond Award for the best paper published by a member of the Institute under 33 years of age to M. Tenenbaum for his paper entitled "Structure, Segregation, and Solidification of Semikilled Steel Ingots."

Alfred Noble Prize (joint award of the Founder Engineering Societies and the Western Society of Engineers) to Robert L. Hoss for his paper entitled "Calculated Effect of Pressure Maintenance on Oil Recovery."

Also at the banquet the following, who have been members of the Institute since 1899, and several of whom will be present, will be inducted into the Legion of Honor:

Eugene Antz
George H. Ashley
H. A. Brassert
John Cabot, Jr.
Norman Carmichael
Arthur Chippendale
Carl R. Davis
T. R. Drummond
Robert J. Grant
Allen C. Hardison
Ernest A. Hersam
Henry M. Lane
C. M. Lewis
J. F. Mitchell-Roberts
Lord Skelmersdale
Harold Abbot Titcomb
J. B. Tyrrell
Archer E. Wheeler
Orvil R. Whitaker
George B. Wilson

Lewis Emanuel Young will be introduced as President of the Institute for 1949.

Technical Program

Detailed individual Branch and Division programs, ranging from practically final to somewhat tentative, may be found in the January issues of the three AIME monthly journals as follows:

Mining Engineering: Mining Methods, Health and Safety in Mines, Minerals Beneficiation Division, Coal Division, Industrial Minerals Division, Extractive Metallurgy Division, Mining Geology, Geophysics.

Journal of Metals: Institute of Metals Division, Iron and Steel Division, Extractive Metallurgy Division.

Journal of Petroleum Technology: Petroleum Division.

Programs of the Mineral Industry Education Division and the Mineral Economics Division appear in the following pages.

See chart on page 14 for schedule of all sessions.

Mineral Economics

Three papers are scheduled for the Tuesday afternoon session on mineral economics and it is hoped to have prominent national figures to present them. The first paper, "America's Stake in the Raw Materials of the World," will point out the tremendous importance of foreign sources of mineral supply to the United States and the need for a dynamic international program to assure a continuing flow of these vital raw materials to American industry. Since strategic materials and stockpiling are an important factor in this situation there should be substantial interest both on the part of Institute members and the general public in what the speaker has to say.

The second paper, entitled "The Future of Gold as a Base for the Monetary Systems of the World," will be presented by a monetary expert not identified with the gold mining industry. An analysis of past trends, the present situation, and the outlook for the future should be of value to the mining industry in general and particularly to that segment of the industry where gold production is an important source of revenue. As the third paper, "International Co-operation in Mineral Production under the Proposed Charter for the International Trade Organization of the United Nations" will deal with the future of cartel and other production-control agreements in the mineral field. The session is under the auspices of the Institute's new Mineral Economics Division.

MIED Program of Widespread Interest

All members of the Institute should look into the program of the Mineral Industry Education Division as there is something of interest to mining, metallurgy, geology, geophysics, and petroleum men. The usual Sunday afternoon and evening sessions will be held in the Hearst Mining Building on the University of California campus, Berkeley. They will be in the nature of forums: afternoon, on mining and metallurgy; evening, geology, geophysics, and petroleum. Two able moderators will lead the discussion: J. R. Van Pelt, Jr., in the afternoon, and E. DeGolyer in the evening. The speakers, men from industry, will have papers on present-day research problems in their own fields and possibly will indicate what the engineering curricula of the future should contain in order to answer better the problems of today and the future. Time will be allowed for discussion toward the end of each session.

A buffet supper at the Men's Faculty Club will follow the Sunday afternoon session.

The Division will hold a third session Monday morning and will meet at luncheon on Tuesday.

Student Forum, Tuesday afternoon.

The program follows (exact titles in final program):

Sunday Afternoon and Evening

Theme: Mineral Engineering Education of the future in the light of present-day research problems.

AFTERNOON SESSION—MINING AND METALLURGY

J. R. Van Pelt, Jr., moderator. C. E. Lawall, Coal Mining; J. H. Rahilly, Metal Mining; A. B. Cummins, Industrial Minerals; D. S. Eppelsheimer, Physical Metallurgy; also papers on Extractive Metallurgy and Mineral Preparation.

BUFFET SUPPER

EVENING SESSION—GEOLOGY, GEOPHYSICS, AND PETROLEUM

E. DeGolyer, moderator. Gustav Egloff, Petroleum Refining and Synthetic Fuels; G. C. Gester, Petroleum Geology; Morris Muskat, Production Research—Present and Future; A. C. Rubel, Production Engineering; W. H. Geis, The Professional Engineer; also paper on geophysics.

MONDAY MORNING

H. E. Nold, Registration of Engineers; J. P. Spielman, Metallurgy Courses; M. I. Signer, Mining Courses; J. D. Forrester, Graduate Study; W. B. Plank, Enrollment Statistics.

TUESDAY NOON

MIED luncheon and business meeting.

Petroleum Division

Four sessions and the annual dinner have been arranged. The production review, Monday afternoon, will consist of eight or nine regional presentations, both domestic and foreign. As at New York last February, these presentations will cover the high lights and exclude detailed statistical material. Tuesday morning will be devoted to economics and it is planned to review the California, national, Canadian, and world oil situations. Prominent and authoritative speakers will be listed in the final program. The two sessions on Wednesday will be on technology and the material in sight may make a session necessary on Thursday morning.

The principal speaker at the dinner on Tuesday evening will be Reese Taylor, president, Union Oil Co. of California. The dinner will be the occasion, too, for the presentation to F. Julius Fohs and J. B. Umpleby of the Division's Certificate of Service Award, which went last year to Earl Oliver, Fred Plummer, and Eugene Stephenson. At the dinner, I. W. Alcorn turns over the gavel to Lloyd Elkins, Chairman for 1949.

At the Sunday evening forum of the Mineral Industry Education Division, E. DeGolyer will act as moderator of the discussion on geology, geophysics, and petroleum. (See MIED program.)

The Institute Research Committee will meet at 4 p.m., Monday.

Robert Hoss will receive the Alfred Noble Prize at the banquet Wednesday evening, for his paper, "The Calculated Effect of Pressure Maintenance on Oil Recovery," published in *Petroleum Technology*, September, 1947.

Metals Branch

The Institute of Metals Division (ferrous and nonferrous physical metallurgy) will hold eight or nine sessions running throughout the meeting; among them, sessions on properties, plastic flow, grain growth and texture, and phase diagrams, three powder metallurgy sessions, a general session, a sintering symposium, and a sintering seminar. Early in the week the Iron and Steel Division will hold four sessions, among them sessions on steelmaking and sulphur in the coke oven and blast furnace. It will also meet with the Minerals Beneficiation Division at the session on pyrolysis and agglomeration and with the Extractive Metallurgy Division on the smelting of titanium ores.

The Metals Branch luncheon (IMD, ISD, and EMD) will be held Tuesday. The Institute of Metals Division Annual Award will be announced at the banquet. The paper for which the award is made this year appears in *Metals Technology,* October, 1946, and is entitled "An Electron Diffraction Study of Oxide Films Formed on Iron, Cobalt, Nickel, Chromium, and Copper at High Temperatures"; authors, E. A. Gulbransen and J. W. Hickman (deceased).

The Annual IMD lecture will be delivered Tuesday morning (11 a.m.) by Egon Orowan, of Cambridge University.

The Howe Memorial Lecture by John Chipman, head, department of metallurgy, MIT, is scheduled for Wednesday morning at 11 o'clock.

Research

The Institute Research Committee, Elmer R. Kaiser, Chairman, will meet at 4 o'clock, Monday.

PAIMEG

The United States Section, Pan-American Institute of Mining Engineering and Geology, will meet at luncheon on Wednesday. Coking possibilities in Colombia may be a topic of discussion.

Mining Methods

Appropriately — in harmony with the Centennial celebration of the California gold rush—the initial paper (Monday afternoon) is "One Hundred Years of Placer Gold Mining in California," by Herbert A. Sawin. The papers—there are six sessions—run the gamut of mining subjects: alluvial mining, opencut mining, drills and drilling, sublevel stoping, caving operations, dump leaching, pumping, etc. A feature is the eight-paper symposium on phosphate mining on Wednesday morning. At the luncheon that day, motion pictures of the old Cornish engines in England will be shown.

Health and Safety in Mines

Monday morning session, avoiding conflict with Mining Methods, four papers, among them, "Safety in Mining at the Andes Copper Mining Company," by Charles M. Brinckerhoff.

Minerals Beneficiation Division

As an appetizer before contemplating the huge technical repast of the MBD, may we suggest the Wednesday afternoon (Noralyn) session, at which will be described the many innovations at the largest and most modern plant of its kind ever built, namely the new phosphate washery of the International Minerals and Chemical Corp., at Mulberry, Fla. Now for the entire bill, by sessions:

Monday morning, coal preparation, Coal Division supplying the program; afternoon, grinding; Tuesday morning, flotation practice; afternoon, flotation theory; afternoon with ISD, pyrolysis and agglomeration; Wednesday morning and afternoon, hydrometallurgy; Wednesday afternoon, jointly with Industrial Minerals Division, Noralyn washery; Thursday morning, gravity separation; Thursday afternoon, "cleanup" session; same afternoon, meeting of Research Committee on Comminution.

The ladies are welcome at the MBD luncheon on Tuesday.

Coal Division

A special three-session symposium on coal preparation, and three sessions on coal-mining problems. The general theme is geared to the growing industrial development of the West and the function of coal in this picture. (Annual luncheon, Tuesday.)

Space does not permit a general survey of six sessions so let's spotlight here and there. Take Monday afternoon: G. A. Vissac, prominent consulting engineer of Vancouver, B. C., will discuss the heat-drying of coal in its technical aspects. The removal of bed moisture from the fine sizes of subbituminous coals in fluidized condition at high capacities will be discussed by V. F. Parry and associates. W. M. Bertholf and J. D. Price will describe a well-tried installation of six vibrating filters for coal sludge which have operated at the Pueblo washery since 1936. So successful has the installation been that it has saved 1400 operating shifts in the washery in the past twelve years, equivalent to a gain of about 2,000,000 tons in production.

Two more quick shifts of the spotlight before the make-up man's scissors start cutting: Tuesday morning session—Another means of clarifying coal-washery water will feature the Dutch cyclone in the opening paper. So successful has been the installation of an experimental but full-size cyclone thickener at the Shamrock, W. Va., mine of the Truax-Traer Coal Co., that several other cyclones have been ordered. This paper is by Thomas Fraser, R. L. Sutherland, and F. F. Giese. Tuesday afternoon, coal mining problems; e.g., trackless mining on steeply pitching thick coal beds in Wyoming, H. C. Livingston, narrator. Wednesday morning, George Hess will show how aerial photography helps in preparing contour maps for strip mines. Coal mining in our nearest-to-Russia frontier in Alaska will be discussed Wednesday afternoon by Albert J. Toenges.

Extractive Metallurgy Division

Five sessions: See chart.

Featured Monday afternoon is a group of three papers concerned with cadmium technology. G. T. Smith and R. C. Moyer describe the fire metallurgy of cadmium; G. H. Anderson describes the electrolytic cadmium practice at Risdon; and P. C. Federsen and Harold E. Lee cover cadmium recovery practice in lead smelting.

Tuesday morning, A. A. Collins reviews the effect of high copper content on the operation of the blast furnace; R. R. McNaughton and associates give results of their experiments with oxygen-enriched air both in the lead blast furnace and in the slag fuming furnace; W. S. Reid discusses sintering practice at the Selby

Smelter; and roasting developments are described in detail by J. A. B. Forster.

Wednesday morning: A three-hour round table discussion on blast-furnace charge preparation and dross treatment, organized by R. R. McNaughton. Casper Nelson will lead off with charge preparation and A. A. Collins will keynote the discussion on dross treatment.

Wednesday afternoon: H. R. Page and A. E. Lee, Jr., trace the development of the modern silicon carbide retorts from the old clay retort; R. R. Furlong and Donald Wertz describe the development of a controlled drying process for zinc retorts at Donora Zinc Works; G. E. Johnson, the development of muffle furnaces for the production of zinc oxide and zinc at East Chicago, Ind.; and T. J. Woodside describes the El Paso slag treatment plant.

The Division meets jointly with the Industrial Minerals and Iron and Steel Divisions Thursday morning for four papers on titanium metallurgy.

Thursday afternoon: Copper; aluminum.

The EMD will join with the IMD and ISD at the annual Metals Branch luncheon on Tuesday.

Industrial Minerals Division

Program somewhat tentative as to distribution of a long partial list of papers (27 at this writing) among eight sessions clearly defined as follows: Monday, resources of the industrial minerals field; afternoon, mineral economics; Tuesday morning, structural materials; afternoon, new products, processes, and techniques; Wednesday morning, jointly with Mining Methods Committee, phosphate symposium; afternoon, jointly with Minerals Beneficiation Division, four Noralyn washery papers; Thursday morning, geology of industrial minerals; Thursday morning, jointly with EMD and ISD, titanium.

Executive Committee meeting, 5 p.m., Tuesday.

Division luncheon, Wednesday noon.

Mining Geology

The Mining Geology Committee and the Society of Economic Geologists meet together for four sessions—Tuesday and Wednesday morning and afternoon. The Committee also meets at luncheon Tuesday noon and the annual dinner of SEG is that evening.

The first two sessions follow an "ore-finding" theme. S. G. Lasky opens with an appraisal of our national mineral resources and there follow papers on the broader features of ore finding and engineering aspects of mineral exploration. H. C. Gunning and Roger H. McConnell will describe the role of certain structural controls in the formation of ore deposits in British Columbia and in the Coeur d'Alene district of Idaho, and Paul F. Kerr and Bronson Stringham will describe alteration effects associated with ore formation in the Silver Bell, Ariz., and Bingham, Utah, districts. R. F. Helmke will review some of the recent outstanding Western iron ore developments and J. J. Collins will describe the important role played by the copper industry in Japan.

To start off the Wednesday morning session, Reno Sales and Charles Meyer, whose paper on the vein alteration at Butte was outstanding at the Annual Meeting last February, are expected to repeat their fine presentation with a paper on the vein formation at Butte. Also on the agenda are descriptions of the Saddle Reef deposits of Bendigo, Australia, and descriptions of four important mining districts in the United States. The Wednesday afternoon session will feature six papers on atomic mineral deposits.

An exhibition of radioactive minerals together with various laboratory and field Geiger counters is planned.

Geophysics

Two sessions: Thursday morning and afternoon.

Atmospheric conditions above the Arctic Circle are much different from those in lower latitudes, with schedules laid down for operations at midnight in summer and hardly one hour with daylight in winter. This is apropos of the paper by Hans Lundberg on aerial magnetic surveys above the Arctic Circle. Dr. Lundberg will show some interesting pictures. Another paper, by Oscar Weiss, reports results with the aerial magnetometer in South Africa. Henry Faul's paper on radioactivity exploration with Geiger counters is in the November *Mining Technology*.

Woman's Auxiliary, AIME

FEBRUARY 13-17

Ladies' Entertainment Committee

Honorary Chairmen

Mrs. William E. Wrather
Mrs. Lewis E. Young

Mrs. H. Robinson Plate, *Chairman*
Mrs. Carlton D. Hulin, *Vice-Chairman*

Registration—Mrs. Granville Borden

Section Reports—
Mrs. Herman A. Prosser

Round Table—Mrs. Newell G. Alford

Membership—Mrs. Henry Y. Eagle

Reception Committee

Mrs. Newell G. Alford
Mrs. W. Sprott Boyd
Mrs. Clifford Bowie
Mrs. Worthen Bradley
Mrs. A. G. Cadogan
Mrs. Frank Girard
Mrs. George L. Harrington
Mrs. W. W. Henry
Mrs. James F. Kemp
Mrs. Jules Labarthe
Mrs. William Wallace Mein
Mrs. William Wallace Mein, Jr.
Mrs. James G. Parmelee
Mrs. A. B. Parsons
Mrs. Herbert A. Sawin
Mrs. J. H. Sampson
Mrs. O. Cutler Shepard
Mrs. George Sibbett
Mrs. Fred W. Varney
Mrs. D. N. Vedensky
Mrs. Livingston Wernecke

The tentative program follows:

MONDAY

Registration, Fairmont Hotel.
All-Institute Luncheon.
Evening Informal Dinner Dance.

TUESDAY

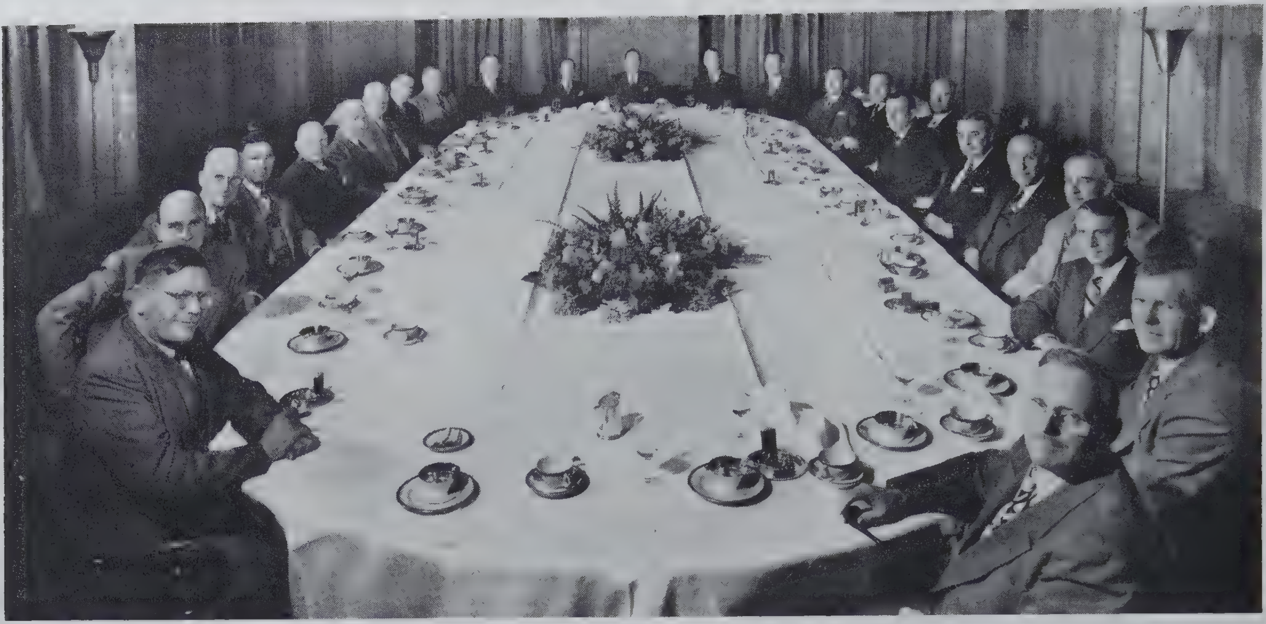
9:45 a.m. Annual Business Meeting.
12:30 p.m. Luncheon. Top of the Mark, after business meeting.
2:30 p.m. Leave by bus from Hotel for tea at Mrs. W. W. Mein's residence in Woodside.
Evening: No planned entertainment.

WEDNESDAY

9:45 a.m. Annual Round Table discussion, Fairmont Hotel; Chairman, Mrs. Newell G. Alford.
12:30 p.m. Luncheon and Fashion Show at St. Francis Yacht Club.
Evening: AIME Banquet. Palace Hotel.

Student Forum Proposed

Because of the success of a young engineers' and students' round table at the El Paso Regional Meeting, a similar session is planned for the Annual Meeting, on Thursday afternoon. Here is a chance for *would be's* to ask questions like: How much will I make on my first job as a mining engineer? Should I work for an advanced degree? What kind of training programs do the companies have? Why don't the mining companies pay as much to recent graduates as the petroleum people do?



Annual Meeting planners gathered at the Pacific Union Club, San Francisco, on Dec. 7 to forward arrangements for the February meeting. Counter clockwise, they include: E. H. Wisser, R. D. Moody, L. A. Parsons, O. P. Jenkins, L. A. Cranson, D. H. McLaughlin, E. L. Oliver, Worthen Bradley, L. C. Uren, W. L. Penick, H. N. Appleton, W. W. Mein, Jr., W. C. Collyer, G. H. Playter, Gilfry Ward, H. A. Sawin, Gordon Gould, P. R. Bradley, Jr., R. M. Searls, H. N. How, S. H. Williston, R. E. Byler, Bernard York, and L. B. Wright.

Setting Up for the Big Blast

Many San Francisco AIME members took a week off from their normal pursuits early in December to meet with Newell Appleton from AIME Headquarters to drive the final wedges in the Annual Meeting setup. It will be your fault if the machine isn't oiled by your making advance hotel reservations and purchasing tickets to social functions. You will want all the time you can get for drilling on Feb. 14 to 17, so clean your working place now so you can make her pay then. San Francisco carries the *lode;* your job is to be set up to start drilling when the air is turned on and to blast before you go off shift. Shift Boss Appleton is preparing a notice to be sent to all AIME members in the United States, Canada, and Mexico which contains full information on how to fill your oil bottle with hotel reservations, advance registration, and tickets to social affairs. You can secure your stope by making out your check to the AIME Housing Bureau, Room 200, 61 Grove St., San Francisco, $5 for one person. $10 for two.

Don't just bring your digging clothes because there is going to be an Informal Dinner Dance on Monday night in Peacock Court of the Mark Hopkins, tickets $7.50 each; a Stag Smoker at the Commercial Club on Tuesday night at $10 apiece; and on Wednesday, the Annual Banquet at the Palace Hotel, also for $10. Full lunch buckets will be provided at various Divisional and Committee luncheons. If things get too tough underground, you can take to the air for a field trip around the Bay industrial area in a Pan American airplane. The only charge for this trip will be for transportation to the airport. On Friday at 8 a.m. a field trip will leave for the San Andreas fault; tickets are $5 per person.

The ore body has been delimited, all we need now is the miners to break the rock. We'll see *you* at San Francisco.

Mrs. H. R. Plate, Mrs. C. D. Hulin, and Mrs. Worthen Bradley, of the Woman's Auxiliary, lunched at the Fairmont on Dec. 8 with H. N. Appleton and (standing) Walter Penick, G. H. Playter, Worthen Bradley, and W. W. Mein, Jr., and made plans for Annual Meeting activities.

Book Reviews

Price Control in the Metal Industries

The History of Basic Metals Price Control in World War II. By Robert F. Campbell. Columbia University Press. 1948. 263 p. $3.25.

Reviewed by Simon D. Strauss

Robert Campbell has diligently assembled a lot of facts about the history of price control during World War II as it affected the iron, steel, and nonferrous metal producers. It does not make exciting reading, possibly because the facts themselves are not too exciting, although at the time there undoubtedly were a good many people who worked up a great deal of high blood pressure over some of these controls.

As is to be expected from an official historian of the OPA, the conclusions are generally favorable to the Office of Price Administration, and the author feels in fact that if any error was made it was on the side of liberality by OPA in allowing price increases, particularly in the steel industry. Professor Campbell apparently is not too well acquainted with the mining and metal industries themselves, for his text gives repeated evidence that he suffers under the customary layman's inability to distinguish between ore and metal. Thus he speaks for instance of several sources of imported ores as being Chile for copper, Mexico for lead, and Mexico, Peru, and Belgium for zinc. Substantially all of our imports of Mexican lead are in the form of metal and not of ore, and, of course, Belgium produces no zinc ore, being an importer of ore and an exporter of metal.

A great deal of attention is paid to the premium price plan, which was largely evolved by OPA officials. Professor Campbell makes much of the fact that this plan had to be literally forced down the unwilling throats of the WPB and the RFC. He refers to the plan as being intended to maintain and expand production of copper, lead, and zinc without greatly increasing the general level of prices, but when he discusses the results of the plan he fails to point out that actually production decreased in all three of the metals from the 1942 level, when the plan went into effect, through the end of the war. Of course, this was not necessarily the plan's fault, since primarily the drop in production reflected a shortage of labor.

On the whole, the book is of value primarily to persons contemplating the re-establishment of price controls in the metal industries in the event of a future war. It is to be hoped, therefore, that it will rest long, comfortably, and undisturbed on the book shelves.

Industrial Air Sampling and Analysis

Veterans and newcomers in the field of industrial hygiene now have recourse to a reference manual, "Industrial Air Sampling and Analysis," by Leslie Silverman, that covers the latest developments on the control of contaminants in workroom air.

The Industrial Hygiene Foundation has just issued this bulletin for the benefit of its member companies, industries interested in advancing employe health and improving working conditions.

Nonmember companies and individuals may order the bulletin for $1.50 from the Foundation's headquarters, 4400 Fifth Ave., Pittsburgh 13.

What Went on at Recent Local Section Meetings

SECTION	DATE	PLACE	PRESIDING OFFICER	ATTENDANCE	SPEAKER, AFFILIATION, AND SUBJECT
Arizona, Ajo Subsection	Nov. 11	Ajo	William Keener	15	John Prendergast, power-plant superintendent, New Cornelia Branch, Phelps Dodge Corp. Discussion of Ajo Power Plant(Phelps Dodge).
Boston	Nov. 1	Smith House, Cambridge	George P. Swift	46	Roscoe J. Whitney, consulting engineer, Leominster, Mass. Hunting Pegmatites from the Air.
Carlsbad Potash	Oct. 22	Carlsbad	R. H. Allport	70	William E. Wrather, director, U. S. Geological Survey. Oil Production in the Middle East.
Carlsbad Potash	Nov. 18	Carlsbad	R. H. Allport	70	T. M. Cramer, vice-president, U. S. Potash Co. Early Developments in the Potash Basin.
Chicago	Nov. 3	Chicago Bar Assn.			Claudia Boyington, editor, industry relations section, *Ceramic Industry*. History and Production of American China.
Detroit	Nov. 22	Detroit		100	F. N. Rhines, Carnegie Institute of Technology. Sintering of Metal Powders.
Lehigh Valley	Nov. 5	Hotel Bethlehem	M. L. Fuller	60	Sherwin F. Kelly, S. F. Kelly Geophysical Services. Geophysics—Twentieth Century Treasure Hunting.
Mid-Continent	Nov. 8	Tulsa	J. Murray Walker	30	Clark Millison, consulting geologist. The Core Recorder. Henry Schaefer, Stanolind Oil and Gas Co. Limestone Pore Space Studies.
New York	Nov. 16	Mining Club			William E. Wrather, director U. S. Geological Survey. Some Aspects of Our Future Mineral Supply Problem.
Ohio Valley	Nov. 3	Engineers Club, Dayton	William A. Mueller	100	Donald B. Gillies, vice-president, Republic Steel Corp. The Future of Iron Resources.
Southwestern New Mexico	Oct. 13	Bayard Lions Club	Ira L. Wright	45	Reports on A. M. C. Convention papers.
Southwestern New Mexico	Nov. 17	Bayard Lions Club	Ira L. Wright	45	Staff members, U. S. Smelting Refining and Mining Co. The Pachuca and Real del Monte Districts of Mexico.
Southwest Texas	Nov. 17	Corpus Christi	Raoul J. Bethancourt	146	H. M. Cooley, Bethlehem Steel Co.: Casing Design Brought Up to Date.
Tri-State	Nov. 12	Picher	O. W. Bilharz	53	J. G. Evans, Gardner-Denver Co. Travelog of Africa.
Utah	Oct. 14	Salt Lake City	W. C. Page	87	T. P. Billings, manager of mines, U. S. Smelting Refining and Mining Co. History of Metal Mining and Mine Operators in Utah.
Utah	Nov. 18	Salt Lake City	J. C. Landenberger, Jr.	51	James K. Richardson, manager Utah Mining Assn. Significant Developments in the Mining Industries' Labor Relations Field.

Among the Student Associates

Colorado School of Mines

Herman Knight was given the President's gavel, to keep for a year, at the Oct. 28 meeting of the Student Chapter at the Colorado School of Mines. Other new officers are: Bill Baker, Secretary-Treasurer; T. A. Hoy and Jack Dempsey, Directors; and George W. Heim, Faculty Sponsor. The members also appointed several committees, giving each at least one senior and one underclassman. Then, under the new leaders, the group outlined a membership drive that should make the Chapter the largest in the country.

The Nov. 18 session of the Student Chapter mixed business with social activities, thereby attracting 112 members. L. W. LeRoy, associate professor of geology at the School, spoke, with colored slides, on the general geology of the Lake Maracaibo region of Venezuela. When finished, Dr. Le Roy was asked questions on foreign employment, as he has had several years' experience working abroad. —*Harvey W. Smith, Public Relations Chairman.*

University of Nevada

Business was dispensed with at the Nov. 3 meeting of the Crucible Club, and Martin K. Hannifan took over for the evening. He is a 1938 graduate of the University's Mackay School of Mines, who recently returned to the States after working as a safety engineer for the Andes Copper Mining Co., in Chile. His talk on foreign jobs, a subject of great interest to his listeners, covered the advantages and disadvantages. An informal question and answer session followed. —*William D. Williams, Secretary.*

Calendar of Coming Meetings

JANUARY

5 **Chicago Section, AIME.**
6 **Reno Branch, Nevada Section, AIME.**
7 **Columbia Section, AIME.**
10 **Mid-Continent Section, AIME.**
10 **Boston Section, AIME. President W. E. Wrather.**
10-14 Society of Automotive Engineers, annual meeting and engineering display, Book-Cadillac Hotel, Detroit.
11 **East Texas Section, AIME.**
12 **El Paso Metals Section, AIME.**
12 **San Francisco Section, AIME. R. A. Kinzie, Jr., on the Lepol kiln.**
12 **Southwestern New Mexico Section, AIME.**
17 **Detroit Section, AIME. Thermodynamics.**
17 **Minnesota Section, annual meeting, Hotel Duluth, Duluth, Minn.**
18 **Gulf Coast Section, AIME.**
18 **Washington, D. C., Section, AIME.**
18-19 Symposium for Mining Engineers, University of Minnesota.
19 **Southwest Texas Section, AIME.**
20 Mineral Industry Institute, 22nd annual meeting, sponsored by School of Mineral Engineering, Univ. of Washington, Seattle. Joint evening session with North Pacific Section, AIME.
20 **Carlsbad Potash Section, AIME.**
20 **North Pacific Section, AIME.**
20 **Utah Section, AIME.**
21 **Oregon Section, AIME.**
24 **Alaska Section, AIME.**
24-28 American Society of Heating and Ventilating Engineers, annual meeting, Chicago.
25 **Montana Section, AIME.**
Jan. 31-Feb. 4 AIEE, winter general meeting, Pennsylvania Hotel, New York City.

FEBRUARY

1 Society for Applied Spectroscopy, 63 Park Row, New York City, 8 p.m. F. Nolan, on fluorescence.
2 **Chicago Section, AIME. S. J. Creswell, on the Bessemer process.**
3 **Reno Branch, Nevada Section, AIME.**
4 **Columbia Section, AIME.**
7 **Boston Section, AIME.**
8 **East Texas Section, AIME.**
9 **El Paso Metals Section, AIME.**
11-12 Association of American State Geologists, San Francisco.
11-12 New Mexico Miners and Prospectors Assn., Santa Fe.
14 **Mid-Continent Section, AIME.**
15 **Gulf Coast Section, AIME.**
15 **Washington, D. C., Section, AIME.**
14-17 **Annual meeting, AIME, Fairmont Hotel, San Francisco.**
Feb. 28-Mar. 4 ASTM, spring meeting and committee week, Hotel Edgewater Beach, Chicago.

MARCH

3-5 Symposium on Southeast mineral resources, University of Tennessee, Knoxville.
10-12 American Physical Society, Div. of Solid State Physics, Hollenden Hotel, Cleveland.
14-17 American Association of Petroleum Geologists, annual meeting, Hotel Jefferson, St. Louis.
Mar. 29-Apr. 1 Annual Safety Convention and Exposition, Hotel Pennsylvania, New York City.

APRIL

18-20 **Open Hearth Conference, and Blast Furnace, Coke Oven and Raw Materials Conference, Palmer House, Chicago.**
24-28 American Ceramic Society, national meeting, Netherland-Plaza, Cincinnati, Ohio.

SEPTEMBER

25-28 **Regional Meeting, AIME, Neil House, Columbus, Ohio.**

OCTOBER

17-19 **Institute of Metals Division, AIME, fall meeting, Cleveland.**

FEBRUARY 1950

12-16 **Annual Meeting, AIME, Pennsylvania (Statler) Hotel, New York City.**

APRIL 1950

10-12 **Open Hearth Conference, and Blast Furnace, Coke Oven and Raw Materials Conference, Netherland-Plaza Hotel, Cincinnati.**

Missouri School of Mines

Almost 200 men got together for the Missouri School of Mines Student Chapter meeting on Nov. 10. The feature of the meeting was Burr Aton, of the Eagle-Picher Co., who presented his multitudinous audience with a talk and film on hygiene in mining and smelting. Mr. Aton discussed health protection for the workers, emphasizing silicosis and dust control. Refreshments followed.—*Albert Jones, Secretary.*

Ohio State University

As the 1948 part of the current school year drew to a close, students in the Mineral Industries Society of Ohio State University had already gone quite a ways in reaching their objective of an active and educational year. At the opening meeting, D. J. Demorest, retiring head of the department of metallurgy, spoke on "How Not to Be a Metallurgist." The other meetings consisted of a movie, "Wealth of the Andes," the introduction of new members, and business. In addition, a vigorous athletic program, directed by William H. Santschi, was started. All these activities were maneuvered by the new officers: Benjamin Roth, President; Thomas L. Chase, Vice-President; and John A. Schumann, Secretary-Treasurer.

At an organization meeting on Oct. 26, the students of petroleum and mining engineering at the Ohio State University formed the Prospectors' Club. Its purpose is to promote a joint understanding of the diversified interests of the petroleum and mining industries. Benson D. Blackie and Hartzel C. Slider were chosen as President and Vice-President respectively.

Yale University

The Yale Metallurgical Society Student Associates, numbering 25, elected their present officers and cast up a whole year's schedule at their Nov. 4 meeting. The returns of the election made D. A. Nankivell President, Harold Margolin Vice-President, V. T. Potter Secretary, and C. H. Stokesbury, Jr., Treasurer. In line with the plans arranged at that meeting, two weeks later members of the Society inspected the foundry of Sargent & Co., at New Haven.—*V. T. Potter, Secretary.*

Current Institute Papers

The following papers in the Institute monthly journals are available to members according to classification of the papers and the expressed desire of the members for the respective journals. Other members may obtain papers by purchasing the indicated issue of the journal at $0.75 per copy. There are no separate copies of the individual papers.

Mining Papers

The Ammonium Sulphate Process for the Extraction of Alumina from Clay and Its Application in a Plant at Salem, Oregon—By W. R. Seyfried. (*September Mining Technology* and *December Metals Technology.*)

A PROCESS: USING CLAY, SULFURIC ACID, and ammonia for the extraction of metal grade alumina. This installation was sponsored by the United States Government for the purpose of finding a substitute for bauxite as a source of alumina for aluminum production.

Radioactivity Exploration with Geiger Counters—By Henry Faul. (*November Mining Technology.*)

A SURVEY OF THE GENERAL PRINCIPLES, recent practice, and new developments in geophysical exploration with radiation counters, as applied to the problems of surface and underground activity measurement, borehole logging, and sample analysis of radioactive rocks and ores.

The Occurrence and Mining of Solid Bitumens in Western Argentina—By Howard A. Meyerhoff. (*November Mining Technology.*)

ASPHALTITE IS BEING MINED AS SOLID fuel in small quantity in Mendoza and Neuquén in west-central Argentina. The industry is handicapped by remote location and by costs that may make it noncompetitive with imported coal. Survival may depend upon development of a chemical industry utilizing the asphaltite as a raw material.

Determination of Room and Pillar Dimensions for the Oil Shale Mine at Rifle, Colorado — By Fred D. Wright and Philip B. Bucky. (*November Mining Technology.*)

THIS PAPER DESCRIBES THE METHOD used for determining the safe room and pillar dimensions for the oil shale mine. The work consisted of a study of the structure of the deposit; determination of the physical properties of the rocks; and centrifugal tests on scale models of the roof and pillars.

Some Postwar Problems of Geological Engineering Education—By W. T. Thom, Jr. (*November Mining Technology.*)

GEOLOGICAL ENGINEERS HAVING EXCEPtional ability and thorough training are being called by the oil and mining companies in ever-increasing numbers.

These requirements probably cannot be met hereafter unless (a) the schools continually improve their "co-op" programs, and (b) unless the schools, the mineral industries, *and the professional societies* interested, see to it that the able high school students, who are "naturals" for geoexploratory work, get suitable orientation and advice before their senior year of high school.

A Review of Rock Pressure Problems—By Richard P. Schoemaker. (*November Mining Technology.*)

A REVIEW IS PRESENTED OF SOME IMportant results of recent research on the rock pressure phenomenon.

Photoelastic model experiments and mathematical analysis throw a new light on the mechanism of rock failure and doming in underground openings. Mathematical analysis also gives a new approach to the problems of subsidence and of "flow" of rocks under high stress.

Petroleum Papers

Stresses Around a Deep Well—By A. J. Miles and A. D. Topping. (*November Petroleum Technology.*)

IN THIS PAPER THE THEORY OF ELASticity has been applied to the rock about a deep well. When the physical properties of the rock and the state of stress existing therein before drilling can be determined or assumed, it is possible to determine analytically the stress concentrations in the rock about the borehole.

Effect of Antifreeze Agents on the Formation of Hydrogen Sulphide Hydrate—By D. C. Bond and N. B. Russell. (*November Petroleum Technology.*)

THE EFFECTS OF VARIOUS ANTIFREEZE agents on the formation of hydrogen sulphide hydrate have been studied. On a molar basis, the relative lowering of T_M (maximum temperature at which solid hydrogen sulphide hydrate can exist in equilibrium with the given solution) is given for various agents.

Gravity Drainage Theory—By W. T. Cardwell, Jr., and R. L. Parsons. (*November Petroleum Technology.*)

THE PAPER PRESENTS A THEORY FOR estimating the rate of gravity drainage of a liquid out of a sand column. Account is taken of the variation in permeability to the liquid as the saturation in the upper part of the sand becomes less than 100 per cent. The theory is confirmed by previously published data.

Revaporization of Butane and Pentane from Sand — By C. F. Weinaug and J. C. Cordell. (*November Petroleum Technology.*)

DATA ARE PRESENTED FOR THE PRESsure depletion of methane-n-butane and methane-n-pentane mixtures from an unpacked and a sand-packed constant-volume cell. The results indicate that the P-V-T equilibrium of these systems is not affected by the presence of sand.

The Effect of Permeability Stratification in Cycling Operations—By Morris Muskat. (*November Petroleum Technology.*)

ASSUMING IDEALIZED RESERVOIR STRATIfication, cycling recoveries are calculated for exponential, probability, and linear permeability distributions. Break-through recoveries are computed for different degrees of permeability variation, and the total wet gas recoveries and associated total gas throughflows until the wet gas content of the flow stream falls to preassigned limits.

The Theory of Potentiometric Models—By Morris Muskat. (*November Petroleum Technology.*)

THE ANALYTICAL THEORY UNDERLYING potentiometric models as analogues of reservoir flow systems is given. The manner of constructing models to simulate systems of variable thickness, permeability, porosity, and fluid density is outlined. It is concluded that isovol models adjusted for variable hydrocarbon porosity will not give correct analogies to actual reservoir fluid motion.

Coal Papers

Oil and Gas Wells Drilled through Workable Coal Seams—By A. J. Alexander. (*November Coal Technology.*)

THE PAPER PRESENTS THE DANGERS that existed when mining coal in the vicinity of uncharted wells prior to the enactment of the Oil and Gas Laws of W. Virginia and the application of these laws, under the direction of the Department of Mines, which tend to safeguard lives and property of the State's two major industries.

The Use of Illinois Coal in the Production of Metallurgical Coke—By F. H. Reed, H. W. Jackman, and P. W. Henline. (*November Coal Technology.*)

AN EXPERIMENTAL COKE OVEN HAS been developed by the authors in which coal blending may be studied. Coking results may be applied directly to commercial oven practice. Studies have shown that prepared coals available from the Illinois field may be used to advantage in modern ovens producing metallurgical coke for blast furnace fuel.

Cleaning Anthracite Silt for Boiler Fuel with Humphreys Spiral Separator — By W. L. Dennen and V. H. Wilson. (*November Coal Technology.*)

The Paper Describes the First Anthracite silt cleaning plant using the Humphreys spiral separator, and the results obtained in the first year's operation.

Determination of Petrographic Components of Coal by Examination of Thin Sections—By B. C. Parks and H. J. O'Donnell. (*November Coal Technology.*)

This Paper Reviews the Bureau's terminology of describing components of coal and type classification of coals from microscopic analysis. It describes experimental tests to determine accuracy achieved in making petrographic analyses of coal by thin-section microscopy and presents data summarizing results. The practical application of analyses of coal by microscopic method is discussed.

Coal Dock Operations of the North Western-Hanna Fuel Co. at the Head of the Lakes—By J. T. Crawford. (*November Coal Technology.*)

This Paper, Which Includes a Brief history of coal dock operations, is largely devoted to a description of operating practices and problems of five coal docks at the ports of Duluth, Minn., and Superior, Wisc. Included are general details of moveable bridges, their associated screening plants and other equipment required for the unloading of bulk coal carriers, the storage on the docks, and the preparation and reloading of coals for distribution by rail and truck into the area serviced by the Lake docks.

Metals Papers

Temper Brittleness of Plain Carbon Steels—By L. D. Jaffe and D. C. Buffum. (*December Metals Technology.*)

It Is Suggested That Plain Carbon steels are susceptible to temper brittleness, and that temper brittleness develops so rapidly in these steels that even drastic quenching from a high tempering temperature is insufficient to suppress it. Limited experimental results support this theory.

Hydrogen in Aluminum—By Y. Dardel. (*December Metals Technology.*)

Suggestion of a New Method to Determine the amount of dissolved hydrogen in liquid as well as in solid metal has been made. The sample is first melted if solid, then held at constant temperature, and the hydrostatic pressure above is slowly lowered. When the first bubble appears, the pressure is read and a nomogram gives the corresponding hydrogen amount. The solubility of hydrogen in solid aluminum is very small. It varies from 0.058 $cm^3/100$ g at 659C to about 0.015 $cm^3/100$ g at 550C.

Lead-grid Study of Metal Powder Compaction—By Robert Kamm, M. A. Steinberg, and John Wulff. (*December Metals Technology.*)

With the Aid of Circular-holed lead grids, it is shown in the present paper that the compaction of metal powder compacts is primarily aided by die wall lubrication. High pressing speeds and vacuum pressing do not appreciably affect green density but may influence sintered density.

Morenci Smelter of Phelps Dodge Corp., Morenci, Arizona—By L. L. McDaniel. (*January Journal of Metals.*)

Operating Practice of the New Morenci smelter, Morenci, Ariz., has never been described, and it is the purpose of this paper to discuss metallurgical and operating practice and to describe structural features of the completed plant and to show drawings, photographs, and tabulations of the results in support of the article.

The Interaction of Liquid Steel with Ladle Refractories—By C. B. Post and G. V. Luerssen. (*January Journal of Metals.*)

The Cleanness of Basic Arc Melted steel is influenced by the manganese and silicon contents. The reaction of liquid steel with ladle refractories, and subsequent contamination of ingots with nonmetallics, account for this effect. Cleaner steel can be obtained if the manganese and silicon contents are made substantially equal.

The Influence of Temperature on the Affinity of Sulphur for Copper, Manganese, and Iron—By E. M. Cox, M. C. Bachelder, N. H. Nachtrieb, and A. S. Skapski. (*January Journal of Metals.*)

Equilibrium Constants of the Reactions $\textit{Metal Sulphide} + H_2 = H_2S + \textit{Metal}$ were measured. The affinity of sulphur for copper is greater than that for iron and exceeds that for manganese above 1350C. It is concluded that increasing amounts of copper in scrap raise the sulphur content of the bath in the open-hearth process.

Plastic Deformation Waves in Aluminum—By Andrew W. McReynolds. (*January Journal of Metals.*)

Plastic Deformation in Aluminum alloys is found to occur not continuously, but by the repeated propagation of plastic waves. The resulting stress-strain curve consists of regularly spaced rectangular steps. The effect results from the presence of alloying elements, probably by precipitation, and occurs only within a range of temperatures.

On the Structure of Gold-silver-copper Alloys—By J. G. McMullin and J. T. Norton. (*January Journal of Metals.*)

The Constitutions of a Number of gold-silver-copper alloys were investigated by X-ray diffraction methods. A two-phase field was found to extend from the silver-copper binary into the ternary system as far as the 75 weight per cent gold alloys. The equilibrium limits of this two-phased region are outlined at several temperatures.

Stress and Strain States in Elliptical Bulges—By C. C. Chow, A. W. Dana, and G. Sachs. (*January Journal of Metals.*)

The Stress and Strain States Found in two elliptical bulges and one circular bulge contour of cartridge (70-30) brass were analyzed. The strains were determined experimentally while the stresses were calculated by using the equation for equilibrium of a shell and several laws of plasticity. In addition the several universal stress-strain relations were studied.

A Study of Textures and Earing Behavior of Cold-rolled (87-89 Per Cent) and Annealed Copper Strips—By Ming-Kao Yen. (*January Journal of Metals.*)

This Paper Deals with the Textures and deep-drawing properties of five types of commercial copper strips after 87 to 89 per cent final reduction and annealing. The influence of impurities, especially phosphorus, is given particular attention. A correlation between the formation of textures and earing behavior is reported.

Use of Electrical Resistance Measurements to Determine the Solidus of the Lead-tin System —By Ralph Hultgren and Stanley A. Lever. (*January Journal of Metals.*)

A Method of Determining the solidus of an alloy by means of electrical resistance measurements taken under equilibrium conditions at successively higher temperatures is described. The method was found to be convenient, reproducible, and highly sensitive. The results agree closely with those of other observers.

Transient Plastic Deformation—By R. P. Carreker, J. G. Leschen, and J. D. Lubahn. (*September Metals Technology.*)

Experiments Performed With Lead, copper, and an aluminum alloy qualitatively confirm predictions made in the preceding paper of transient effects in deformation. The effects of sudden changes in stress, temperature, and strain rate, and of cyclic loading are considered.

News of AIME Members

Don U. Deere is on leave of absence from the University of Puerto Rico and is doing graduate work in geology at the University of Colorado, Boulder.

Alfred S. Geldman, who had been resident engineer in charge, American Silver Corp., Los Angeles, is now assistant superintendent of the Monolith Portland Cement Co., Monolith, Calif.

T. S. Lovering, of the U. S. Geological Survey, delivered a lecture at the University of Kansas on Nov. 22 on "The Drive for Minerals."

W. W. Taylor has been with Stone & Webster since his return from Chile and is now in charge of their work on the construction of the Texas Gas Transmission Corporation's gas line from Carthage, Texas, to Middletown, Ohio. He may be addressed in care of that company, Steuck Bldg., Memphis, Tenn.

With the Mining Men

John R. Castano, who graduated from the College of the City of New York last June, is now a graduate assistant in geology at Northwestern University, Evanston, Ill.

John C. Chew graduated from Penn State last June with a B.S. degree in mineral economics and geology. Since then he has been working with the Phelps Dodge Copper Products Corp. as an engineer in a trainee capacity. The program is designed to acquaint the fledgling engineer with the various plants or those of most importance. He has worked at the wire and tube mill in the Bayway plant at Elizabeth, N. J., and at the Inca Mfg. division (enameling and insulation) at Fort Wayne, Ind. About the middle of January he expects to be transferred to the Habershaw division at Yonkers, N. Y., for the final phase of training.

George Bryan Coggins has been shifted to the Asheville, N. C., office of Bee Tree Vermiculite Mines, Inc. His mail goes to 201 Public Service Bldg.

In the first issues of the new magazines we are glad to tell members of the engagement of **Irene P. Klein** and **Ernest H. Sharp.** Wedding bells will ring Jan. 15. Members who visit Institute headquarters know Miss Klein as the friendly person who greets them as they step off the elevator, and who helps them with their problems, both professional and personal. Mr. Sharp, a Michigan College of Mines man, has worked in South America for the Anglo-Chilean Consolidated Nitrate Corp. and Cerro de Pasco, and in the States more recently with the Bureau of Mines, the FEA in Washington, and is now with Eagle-Picher in New York City.

Evan Bennett has moved to Chattanooga, Tenn., and resides at 4104 St. Elmo Ave.

Charles M. Brinckerhoff has been appointed general manager of the Chile Exploration Co. at Chuquicamata, Chile. **N. F. Koepel** takes over as general manager of the Andes Copper Mining Co. and the Potrerillos Railway Co. in Mr. Brinckerhoff's stead.

Edwin H. Crabtree, Jr., now of Eagle-Picher Mining and Smelting Co., First National Bank Bldg., Miami, Okla., has gone there from Tucson, Ariz.

William E. Crawford, former mill superintendent of Berens River Mines Ltd., is now addressed in care of the Quemont Mining Corp., Noranda, Que.

Forbes B. Cronk, general mining engineer for Oliver Iron Mining Co., receives his mail at 2416 East Third St., Duluth 5, Minn.

Robert J. Dalton is president and general manager of the Faire Mining Corp., 511 Baseline, San Bernardino, Calif.

James S. Dodge, Jr., wrote on Oct. 18 from his address, Natural Resources Section, GHQ, SCAP, APO 500, San Francisco, that he had made recently a field examination of the large Matsuo pyrite-sulphur mine in Iwate Prefecture. He had with him a copy of the August M&M and the article on the Greater Butte project was read avidly by the Japanese. He says that it is unfortunate that most of the Japanese mining industry is unable to obtain up-to-date American mining literature. Lack of a world monetary exchange rate prevents it.

J. Ward Downey has severed his connection with the Westvaco division of Food Machinery and Chemical Corp. For the past two years he has been mine superintendent at their property in Green River, Wyo., sinking a shaft and developing a large deposit of trona. His new address is Rm. 204, 1045 Sansome St., San Francisco, where he is engaged in consulting work, specializing in mine design and development.

Elmer R. Drevdahl, Jr., is working as a mining engineer on the engineering staff of the Inter-State Iron Co., Hibbing, Minn.

Joseph B. Elizondo has been acting as assistant geologist for the Cerro de Pasco Copper Corp., Cerro de Pasco, Peru, since his arrival in August.

R. H. S. Ewins, formerly with Lake George Mines, Captain's Flat, N.S.W., is now addressed Uruwira Minerals Ltd., Private Bag, Tabora, Tanganyika, Africa.

Norman R. Fisher, well-known mining specialist of Montreal, has been made chief consultant and mining engineer for the Greatlakes Copper Mines. He has prepared a report on drilling and the general operations at the property near Kashabowie in the Port Arthur mining division.

Victor G. Ford transferred from his job as manager of the Canutillos-Colavi section of the Bolivian Tin and Tungsten Mines Corp., to that of general manager of Cia. Minera y Agricola Oploca de Bolivia, Chocaya, on Sept. 1.

Frank W. Fruitman was honored recently by the British Government when he was named honorary officer of the military division of the Most Excellent Order of the British Empire. Colonel

Fruitman, whose address is 2919 E. 19th St., Tucson, Ariz., returned to the States last year from Germany, where he was in charge of mining and metallurgical operations in that country's western occupied zone. Before the war he was a mining and metallurgical engineer working in Arizona and California.

E. A. Gee has left College Park, Md., for Wilmington, Del., where he is a metallurgist in the pigments department of E. I. du Pont de Nemours & Co., Inc.

Paul W. Graff, president of Westmoreland Mining Co., Blairsville, Pa., will be receiving his degree in mining engineering this June from Pennsylvania State College.

Norman L. Grauerholz resides in Memphis, Nebr., where he is employed by the C. B. & Q. R. R. Co.

Stanley M. Moos

Stanley M. Moos has resigned as president and general manager of the Western Machinery Co., Mexico City, to establish a new company, Ponsford-Moos Equipment Co., 100 Texas St., El Paso, Texas. The aim of the company is to sell and service mining equipment in the southwestern United States, Mexico, and Central America.

Sydney E. Helprin is now a geologist in the Frick Laboratory, Roslyn, L. I., N. Y.

Howard R. Hendricks is doing special metallurgical research work for the Mt. Isa Mines Ltd., Mt. Isa, Queensland, Australia. He will be there for about one year as he is only on loan from the Shattuck Denn Mining Corp.

Arne Hofseth joined the staff of Aktieselskapet Sydvaranger as superintendent of their iron mines at Kirkenes, Norway, in November. He had been employed for thirteen years as a mining engineer by A. S. Sulitjelma Gruber.

A. Allan Bates

A. Allan Bates can be reached at the Portland Cement Association, 33 West Grand Ave., Chicago, Ill. He is vice-president of the Association.

Frederick C. Green has been promoted to assistant general manager of the Chino mines division of the Kennecott Copper Corp., at Hurley, N. Mex. He has been with Kennecott since 1939, serving as mill superintendent and general superintendent of Chino mines.

C. S. Gwynne, who had been teaching at Mayaguez, Puerto Rico, has returned to his home in Ames, Iowa, where he resumes his work at Iowa State College as associate professor of geology.

James Allen Haertlein, on returning from Maracaibo, Venezuela, where he was employed by the Creole Petroleum Co., has settled at 44 Marion Rd., Watertown 72, Mass.

Bernhard K. Haffner can be reached care of the American Embassy, The Hague, Netherlands. He is working with the ECA Mission to The Netherlands.

Dennis F. Haley now lives at 29 East 64th St., New York, N. Y.

W. A. Hardy returned on Oct. 28 to India to resume his duties as agent and general manager of the Central Provinces Manganese Ore Co., Nagpur, C. P., India. He had been in England.

J. S. Hazen has migrated from Holyoke, Mass., to Hamilton, Ill., P. O. Box 285.

Arthur S. Hecht, consulting mining engineer for the Department of Commerce, USAFIK, Korea, recently returned from Korea to the States. He is being retained by the Civil Affairs Division of the Army to act as consultant on technical matters concerning ore beneficiation tests now in progress in this country. At present he may be contacted at 342 27 Ave., San Francisco 21.

Warren L. Howes is with Western-Knapp Engineering Co., at 220 Power Bldg., Hibbing, Minn.

H. Herbert Hughes of the Studebaker Corp. is working for the ECA in Paris. He can best be reached now by addressing him Paris (ECA), care of Department of State Mail Rm., Washington 25, D. C.

Charles F. Joy, formerly with the International Smelting and Refining Co. as assistant geologist at the North Lily mine in Eureka, Utah, is now resident geologist at the Shoshone division of the Anaconda Copper Mining Co. in Tecopa, Calif.

M. R. Klepper, geologist for the USGS, receives his mail at 157 So. Howard St., Spokane 8, Wash.

James A. Knight, who was in Reno, Nev., is now at 231 East Sixth St., Hinsdale, Ill.

F. Clyde Lendrum is now mill superintendent for Anacon Lead Mines Ltd., Montauban Les Mines, Portneuf County, Que. He was formerly with Normetal Mines Corp.

Charles A. Lindsay is production manager for the Los Angeles division of Stauffer Chemical Co. His residence is 533 Via Media, Palos Verdes Estates, Calif.

Jimmie A. Littrell, a student at the University of Arizona, lives at 53-A Polo Village, Tucson, Ariz.

Victor M. Lopez is with the Organizacion Internacional de Investigaciones, Industriales de Venezuela, Caracas, Venezuela.

Anthony M. Mastrovich, formerly with the U. S. Vanadium Corp. at Uravan, Colo., as engineer and geologist, is exploration engineer in the western mining department of the American Smelting and Refining Co., Pacific National Life Bldg., Salt Lake City.

George E. McCormack, who has been at the Missouri School of Mines, is now working in the engineering department of the Hatfield-Campbell Creek Coal Co., Rensford, W. Va.

C. E. Miller has assumed the post of chief mining engineer with his present employers, Chrestien Mica Industries, Ltd., Domchanch P. O., Via Kodarma E. I. Rly., Behar, India.

Maurice A. Moore has moved from Kalgoorlie, W. Australia, to Ferry Rd., Southport, Queensland, Australia. He is with Associated Minerals Pty. Ltd.

Adolph E. Parr has left sunny California for Nome, Alaska. His box number is 438.

Nels P. Peterson has left University Station, Tucson, Ariz., and is no longer available for consulting work. His new address is Box 1211, Globe, Ariz.

George W. Roddewig, consultant to the American Zinc, Lead and Smelting Co., may now be addressed at 108 S. Glenroy Ave., Los Angeles 24.

Adolph E. Sandberg is professor of geology at Lousiana State University, Baton Rouge, La.

J. Watts Scott is supervisor of mineral leases for the Tennessee Coal, Iron and Railroad Co. His mail will reach him at Rt. 1, Box 43, Jemison, Ala.

Joe W. Stewart, whose residence is 810 N. W. 41st Ave., Miami, Fla., is hydraulics engineer for the USGS.

Charles G. Tebelman, Jr., is employed by the Bethlehem Steel Co., 700 E. Third, Bethlehem, Pa.

Wilber D. Walker resides at 213 So. 9th Court, Bessemer, Ala., and is acting as industrial engineer for the Tennessee Coal, Iron and Railroad Co.

Louis Ware, president of the International Minerals and Chemical Corp., has been elected a director of the Illinois Central Railroad Co. Mr. Ware has worked in Arizona, Chile, New York, and Chicago with several well-known companies and has been with International Minerals since 1939.

Judson H. Whitman has moved south from Ketchikan, Alaska, to work in the engineering department of Pend Oreille Mines and Metals Co., Metaline Falls, Wash.

John Weldon Wilson is agent for Shell Oil Co., Las Vegas, Nev. His mail should go to P. O. Box 350 there.

Bernard York is now engaged as assistant professor of mining at the University of California, Berkeley 4, Calif.

• In the Metals Divisions

John S. Absalom is attending the Missouri School of Mines and makes his residence at 1804 Oak St., Rolla, Mo.

Karl Anson Allebach is employed as a supervisor for North American Aviation, Inc., and commutes to work from his residence at 306 Georgina Ave., Santa Monica, Calif.

William J. Bannister is manager for the Wire Mills Products Division of British Insulated Callender's Cables Ltd., Prescot, Lancashire, England.

William H. Bassett, Jr., Lieutenant Colonel in the United States Army, has trekked south from Scarsdale, N. Y., to Birmingham, Ala. His mail should be sent in care of Birmingham Ordnance Division, 734 Frank Nelson Bldg.

William Raymond Bay, Jr., is employed by Irvington Smelting and Refining Works at Irvington 11, N. J.

Thomas E. Miller, after completing his studies at the University of Kansas, joined the Oklahoma Steel Castings Co., in Tulsa.

J. B. Carlock is now chief consulting engineer for the Loftus Engineering Corp., 610 Smithfield St., Pittsburgh 22.

R. Allen Crosby is a metallurgist for Carnegie-Illinois Steel Corp. and lives at 2120 East 73rd St., Chicago 49, Ill.

George M. Gordon, chief chemist, U. S. Naval Dry Docks, Hunters Point, San Francisco, is in residence at 15 Stephens Way, Berkeley 5, Calif.

Harry P. Croft

Harry P. Croft, former director of technical control and research for Chase Brass and Copper Co.'s Midwestern division, has been named vice-president in charge of development of the Wheeling Bronze Casting Co., Moundsville and Wheeling, W. Va. He had been associated with Chase Brass in various capacities, including chief metallurgist, for 26 years. Dr. Croft, a graduate of Rensselaer Polytechnic Institute, received his Ph.D. degree in metallurgy from Case Institute of Technology in 1942.

Robert T. Howard has resigned from his job with the Los Alamos Scientific Laboratory and has joined Black, Sivalls & Gryson, Inc., 7500 E. 12th, Kansas City, Mo., where he will be associated with the quality control director.

Hjalmar W. Johnson

Hjalmar W. Johnson was recently named vice-president in charge of steel manufacturing for the Inland Steel Co. Mr. Johnson went to Inland in 1929 as assistant superintendent of blast furnaces. In 1930 he was promoted to superintendent of blast furnaces. He was made assistant general superintendent of the Company's Indiana harbor works in 1942 and remained there until 1946 when he was appointed staff assistant to the president.

Clarence B. Randall has been named assistant to the president of the Inland Steel Co. He had been vice-president in charge of raw materials since 1930. Well-known in the steel industry, Mr. Randall came to Inland Steel in August, 1925, as assistant vice-president. A graduate of Harvard University, he had previously practiced law in Ishpeming, Mich.

Wilfred Sykes' term of office as Inland Steel Co. president was recently extended by the board of directors beyond his normal retirement date of Dec. 31, 1948. He will continue his services thereafter in such capacity and for such period of time as the directors may subsequently determine.

Carl S. Wiedman is research metallurgist for the Carboloy Co., Detroit. His address is 5281 Beaconsfield, Detroit 24, Mich.

• In Petroleum Circles

Ray W. Amstutz is a petroleum engineer for Earlougher Engineering and can be reached at 319 E. 4th, Tulsa.

Edward I. Barton, junior geophysicist for Gulf Research and Development Co., receives his mail at Box 1096, Shawnee, Okla.

Frank W. Abrams

Frank W. Abrams, chairman of the board of the Standard Oil Co. of N. J., has been made national chairman of the forthcoming $15,000,000 Syracuse University building and development fund. Mr. Abrams received his civil engineering degree from the College of Applied Science at Syracuse in 1912 and an honorary LL.D. degree from the University in 1946.

E. M. Benson, Jr., petroleum engineer for the Richfield Oil Corp., may now be addressed at Box 147, Bakersfield, Calif.

Byron B. Boatright is now vice-president of the Conroe Drilling Co. with an office in the Brown Bldg., Austin, Texas.

Don R. Bowcutt, formerly of Butte, is an engineering clerk for Phillips Petroleum Co., Cut Bank, Mont.

Stuart G. Branyan, district engineer for the Carter Oil Co., receives his mail at Magnolia, Ark.

Chester U. Burk has left Texas for Oklahoma City. His mail goes care of Kobe Inc., Box 4515, S. E. 29th St., Oklahoma City.

Robert A. Cadigan is working for the USGS on the Colorado plateau project at Grand Junction, Colo.

George R. Chenot is now geologist for the Standard Oil Co. of Texas, at Dallas.

Wallace H. Collins is now with Shell Oil Co., Inc., Box 1191, Tulsa.

Maurice Deul has a job in the section of geochemistry and petrology of the U. S. Geological Survey, Washington 25, D. C.

Norman S. Domenico, after graduation from the Colorado School of Mines last spring, worked as a computer on a seismograph crew of the Atlantic Refining Co. in Wyoming. This fall he enrolled as a graduate assistant in the geological sciences division of the California Institute of Technology and is now studying toward an advanced degree. His address is 1126 Cordova, Pasadena 5, Calif.

Jules A. Durand is inspector of mines in Seine et Oise Province, France.

Wesley G. Gatlin is training as a petroleum engineer for The Texas Co. at Houma, La.

Jerry V. George is temporarily at A & M College of Texas but receives his mail at Rt. 1, Milford, Texas.

Walter F. Gerhard, with Amerada, may now be addressed at P.O. Box 103, Los Alamos, Calif.

Lee W. Gibson, consulting geological engineer, makes his office at 616 Indianapolis, Huntington Beach, Calif.

James L. Minahan

James L. Minahan, geologist for the USGS, receives his mail at Box 590, Thermopolis, Wyo.

Edward H. Griswold, petroleum engineer, has moved from Midland, Texas, to Pebble Beach, Calif.

Ellis W. Hamilton is doing production and drilling work for Kern Oil Co., Ltd., at Bakersfield, Calif.

John L. Hoyt, Jr., is assistant general superintendent for Pan American Production Co., Mellie Esperson Bldg., Houston, Texas.

Clarence B. Hussey, formerly with Gulf at Kermit, Texas, has been transferred to Odessa, Texas, where he is zone petroleum engineer for the Gulf Oil Corp.

Julian E. Huzarevich, recently of Fort Worth, is now a junior petroleum engineer for Stanolind Oil and Gas Co., Tulsa.

David J. Kull is an exploration trainee with Shell Oil Co. at Houston.

Robert M. Leibrock has moved from Arkansas to 619 N. Osage Dr., Tulsa.

W. T. Mendell is now working for himself. He will be doing consulting petroleum geology and engineering; his office is 1902 Second National Bank Bldg., Houston, Texas.

Gregor C. Merrill is Paris representative for United Overseas Petroleum Co., Ltd. His mail should be sent to 7 Place Vendome, Paris 1.

Harold L. Moseley is a petroleum engineer for D & W Oil Tool Co., Inc. He should be addressed Box 1215, Corpus Christi, Texas.

L. Murray Neumann, formerly consulting geologist with the Carter Oil Co. of Tulsa, has opened an office at 412 Palace Bldg., Tulsa.

Basil V. Savoy, who was with Central Pipe Line Co., is now a petroleum engineer for Continental Oil Co., Houston, Texas.

Ralph J. Schilthuis, assistant superintendent of the gas division for Humble Oil and 1939 Alfred Noble Prize winner, resides at 3747 Purdue, Houston.

Raymond D. Sloan has been shifted by the Carter Oil Co. from Billings, Mont., to Denver.

Dallas R. Staples, field engineer with The Texas Co., gets mail at Box 1, Premont, Texas.

Karl R. Tripp, a trainee of The Texas Co., has been moved to Pampa, Texas.

Owen M. Watkins, Jr., is now junior production engineer for the Pan American Production Co., 108½ Chaparrel, Corpus Christi, Texas.

F. Raymond Wheeler, of Chemical and Geological Laboratories Inc., has migrated from Tulsa to the Casper, Wyo., office.

Obituaries

Harold S. Munroe

A Tribute by Wilber Judson

THE many friends of Harold S. Munroe ("Jack") were deeply grieved to hear of his passing away in Miami, Fla., on Oct. 15. He had had several heart attacks during the past few years but had recovered from all of them, so he was fairly active and, while not being able to take too much responsibility, was enjoying good health and comfort. His sudden death is therefore a special shock.

Munroe had a wonderful personality, making friends easily and keeping them.

His sense of humor was delightful and it was a pleasure to be in his company. Few mining engineers have had the wide friendships he enjoyed, both in the United States and abroad, especially in England. He also had many close friends among the hard-rock miners in different parts of the world. Everyone liked him—a great tribute to any man.

I first met Munroe in Panama in 1906. Both of us were on our way to take jobs in a copper mine, in the Argentine, which closed down the following year in the depression of 1907. After that we were together in Mexico most of the time—in fact, until Munroe left there around 1913. Since that time it was my pleasure to see him fairly often, so we renewed our old friendship as often as possible.

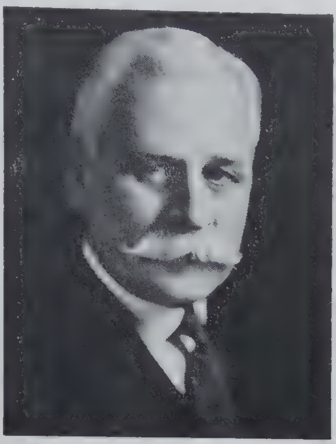
After leaving Mexico he, in turn, was general manager of the Consolidated Coppermines in Nevada; vice-president and general manager of the Granby Consolidated Mining, Smelting and Power Co., with headquarters at Anyox, B. C.; mining engineer for The American Metal Co.; and mining engineer with the Newmont Mining Corp. Through Newmont he was employed as consulting engineer for the Rhokana Corp., owning and operating copper mines in Rhodesia. In his capacity as general manager of the Rhokana operations, he had the responsibility for equipping and operating the mine, mill, and smelter at the N'Kana mine in Northern Rhodesia—one of the largest copper mines of the world. In 1935 he returned to North America and became director and consulting engineer for Ventures, Ltd., living in Toronto. I believe it is correct to say that he was one of the great mine operators of his generation, having a flair for building and handling an organization such as few men possess.

While in Toronto he had his first heart attack, incapacitating him for continuous strenuous effort. After leaving Toronto he moved to Fort Lauderdale, Fla., and a little over a year ago he moved to Tryon, N. C. Munroe's scholastic training was at Cornell and the Colorado School of Mines. He will be missed by his many friends for whom a visit with him was a most pleasant event and happy memory.

RANDOLPH SIMPSON (Member 1940), chief metallurgist for the Electric Steel Foundry Co., died recently at his home in Portland, Oreg. A native of Massachusetts—born there 62 years ago—he migrated to Portland in 1912, soon after receiving a B.S. from Dartmouth College. In that city he did chemical work for the Santa Cruz Portland Cement Co. and the Portland Gas and Coke Co., before he went to Electric Steel. This last professional association was made in 1920.

Necrology

Date Elected	Name	Date of Death
1923	John Allen Coe	Aug. 4, 1948
1912	Frederick G. Cottrell	Nov. 16, 1948
1907	William H. Emmons	Nov. 5, 1948
1934	H. Clarence Horwood	Oct. 30, 1948
1917	Myril L. Jacobs	Nov. 13, 1948
1912	Harold S. Munroe	Oct. 15, 1948
1940	Randolph Simpson	Unknown
1926	Edward B. Snyder	April 25, 1948



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John Allen Coe

JOHN ALLEN COE (Member 1923), who retired recently after spending sixty years in the brass business, passed away Aug. 4, shortly before his eightieth birthday. Mr. Coe was introduced to that business through the Birmingham Brass Co., with whom he spent the first nine years of his career. When he left it, he joined the American Brass Co., in Waterbury, Conn., as a sales manager. But soon he was advanced, successively, to the positions of assistant to the president, vice-president, and president. Although he "retired" in 1945, he retained a connection with the Company, as a director.

FREDERICK GARDNER COTTRELL (Member 1912), a humanitarian who expressed his benevolence for society as a chemist, metallurgist, and inventor, died Nov. 16, while attending a business meeting of the National Academy of Sciences, at the University of California, in Berkeley. His death concluded 71 years of trying to further the comfort and well-being of humanity. And he was successful in his efforts, mainly through the Research Corp.

Dr. Cottrell established this nonprofit organization in 1912, in order to make his electrical precipitator available to everybody; he rejected the opportunity to take for himself the profits from his invention. In the years that followed, Dr. Cottrell saw that the Research Corp's profits went back into more research, in colleges and scientific institutions. To date, the organization has provided approximately $3,500,000 for scientific research, and the bulk of that sum has come from Dr. Cottrell's invention.

He perfected the electrical precipitator that bears his name between 1906 and 1909, while an assistant professor of chemistry at the University of California, his first *alma mater*. The other two schools he attended are the University of Berlin, where he earned an M.A. degree, and the University of Leipzig, where he earned a Ph.D.

When he left his teaching work, Dr. Cottrell joined the Bureau of Mines as a consulting chemist. From this position he was appointed, consecutively, chief physical chemist, chief chemist, chief metallurgist, assistant director, and director. During the time he was with the Bureau he developed a process for manufacturing helium gas at a cost that made it practical for popular use. He also did considerable work in the metallurgical field toward developing equipment for preheating air used in metallurgical operations.

Among his many other accomplishments was the formation of Research Associates, also a nonprofit organization. Through it, Dr. Cottrell conducted scientific and social research, attempting to eliminate, as far as possible, the time lag between the perfection of scientific ideas and their introduction into national life.

MYRIL L. JACOBS, vice-president of Bethlehem Steel Co.'s raw material properties, died Nov. 13 at the Pan American guest house, Trinidad, B. W. I., of a circulatory failure. He had been taken ill the previous evening at Bethlehem's Palua mine and flown to the Piarco airport.

Mr. Jacobs was born May 16, 1885, at Weldbank, Pa. He received his early education in the schools of the community and at Marietta College and Mercersburg Academy. In 1910 he was graduated from Lehigh with a degree in mining engineering.

He began his business career as assistant engineer for Astoria Light, Heat and Power Co. that same year. In 1912 he was employed by the Mexican Light and Power Co. as assistant engineer in charge of hydroelectric tunnels and dams. The following year he accepted a position as assistant engineer with the New York Municipal Railways in Brooklyn. In 1916 he became engineer for F. H. Clement & Co. at Bethlehem, Pa., and continued in this position until 1920.

At that time he was made general manager of quarries, for Bethlehem Steel Co., in 1934 general manager of the stone and slag division, and in 1939 assistant to the vice-president. The next year Mr. Jacobs was appointed vice-president of Bethlehem Steel Co. and president of various Bethlehem subsidiary companies engaged in mining. He was elected a director of Bethlehem Steel Corp. on Jan. 25, 1940.

EDWARD BEISEL SNYDER (Member 1926), a mining engineer who devoted his entire professional career to service with the Hazle Brook Coal Co., died on April 25, at the age of 57. Mr. Snyder first worked about the Hazle

Brook anthracite mines, in Pennsylvania, during his summer vacations, while a student at Lehigh. After graduation in 1914, with the degree of E.M., he started his career with the Company on a full-time basis. However, three years later, World War I intervened, and he joined the U. S. Army Artillery as a Private. When he was discharged from service in 1919, as a Second Lieutenant, he returned to Hazle Brook, and there remained until his recent death.

Proposed for Membership

Total AIME membership on November 30, 1948, was 15,433; in addition 3687 Student Associates were enrolled.

Admissions Committee

Albert J. Phillips, Chairman; James L. Head, Vice-Chairman; George B. Corless, T. B. Counselman, George C. Heikes, W. B. Plank, P. D. Wilson, E. M. Wise.

Institute members are urged to review this list as soon as the issue is received and immediately to wire the Secretary's office, night message collect, if objection is offered to the admission of any applicant. Details of the objection should follow by air mail. The Institute desires to extend its privileges to every person to whom it can be of service but does not desire to admit persons unless they are qualified.

In the following list C/S means change of status: R, reinstatement; M, member; J, Junior Member; A, Associate; S, Student Associate; F, Junior Foreign Affiliate.

ALABAMA

Adamsville — Marshall, Clarence Ganes. (M). Electrical engineer, coal mines, Tennessee Coal, Iron and Railroad Co.

ARIZONA

Humboldt — Zinkl, Andrew Joseph. (R,C/S—S-M). Assistant superintendent, Iron King branch, Shattuck Denn Mining Corp.

CALIFORNIA

Alhambra—Elson, William Harold, Jr. (R,C/S—S-J). Petroleum engineer, Shell Oil Co. Gardner, John Willis. (R,C/S—S-M). Field engineer, Gardner-Denver Co.

Bakersfield — Charles, William Wathen, Jr. (C/S—J-M). Geologist, Pacific Western Oil Corp. Weller, Arthur Reilly. (J). Junior exploitation engineer, Shell Oil Co.

Berkeley—Pask, Joseph A. (M). Associate professor of ceramic engineering, division of mineral technology, University of California (Berkeley).

Grass Valley—Krebs, Richard William. (M). Mill superintendent, Idaho Maryland Mines Corp.

Hammonton—Pratt, Morton Edison, Jr. (C/S—S-J). Research engineer, Yuba Cons. Gold Fields.

Hollywood — Penn, Charles James. (M). Editor, *Petroleum Register.*

Keeler — MacKevett, Edward Malcolm, Jr. (C/S—S-J). Junior geologist, minerals section, U. S. Geological Survey.

Los Angeles—Maclean, Norman Ewen. (M). Southwestern sales manager, American manganese steel division, American Brake Shoe Co. Natcher, Stanlus Z. (M). Assistant to the vice-president of conservation, Standard Oil Co. of California. Pearson, Gerald Thomas. (C/S—J-M). General production superintendent, Continental Oil Co. Werner, Scott John. (J). Petroleum engineer, Socony Vacuum Oil Co.

Placentia—McNeill, James Michael. (M). Assistant to vice-president, Union Oil Co. of California.

San Francisco—Utt, Ralph Bernard. (M). General sales manager, Western Machinery Co. Wyner, Alexander S. (R, C/S—JA-M). Mining engineer, Pittsburgh Testing Laboratory.

San Jose—Jack, Orville E. (M). Chief chemist, Permanente Cement Co.

Saratoga—Pronger, Norman William, Jr. (C/S—S-J). Miner, Sunshine Mining Co.

South Gate—Alexander, James Frederick. (J). Division engineer, California division, Lane-Wells Co.

COLORADO

Denver—Gardner, Everett Matthews. (M). District manager, Sheffield Steel Corp.

CONNECTICUT

Kensington — Spencer, Lester Fuog. (M). Chief metallurgist, Landers Frary & Clark.

New Haven—Flawn, Peter Tyrell. (J). Geologist, P-1, U. S. Geological Survey.

FLORIDA

Bartow—Becker, John Nathan. (J). Mining superintendent, Virginia-Carolina Chemical Corp. Sherertz, Joe Raymond. (M). Chemical engineer, Davison Chemical Corp.

Lakeland—Fenske, Douglas Hugh. (C/S—S-J). Junior research engineer, International Minerals and Chemical Corp. Long, Joseph C. (M). Flotation plant superintendent, Virginia-Carolina Chemical Corp.

Mulberry—Clark, Raymond Harold. (M). President, R. H. Clark Equipment Co.

IDAHO

Patterson—Anderson, John Sanford. (C/S—J-M). Mill superintendent, Ima mine, Bradley Mining Co.

ILLINOIS

Chicago — Nicholson, Morris Emmons, Jr. (C/S—S-M). Research metallurgist, Standard Oil Co. (Indiana). Watson, Raymond Edward. (J). Assistant petroleum engineer, Standard Oil Co. (Indiana).

Flossmoor—Eisaman, Jack H. (M). Superintendent, No. 2 electric furnaces, Carnegie-Illinois Steel Corp.

Waukegan—Prest, J. Irving. (M). Metallurgist, Johnson motors division, Outboard Marine and Mfg. Co.

INDIANA

Evansville — Samuel, David Griffith, Jr. (R,C/S—J-M). Sales engineer, Harnischfeger Corp.

Wabash—Eckes, LeRoy John. (J). Research analyst, American Rock Wool Corp.

KANSAS

Independence — MacIvor, Roderick Ken. (J). Water flood engineer, Sohio Petroleum Co.

Ulysses—Wagner, Robert James. (J). Junior petroleum engineer, Stanolind Oil and Gas Co.

KENTUCKY

Madisonville — McCloskey, John Robert. (R,C/S—J-M). Sales-service engineer, Hercules Powder Co.

LOUISIANA

Benton—Mills, Earnest Jerome. (M). Project superintendent, Barnsdall Oil Co.

Lafayette — Parker, Joseph Bright. (J). Junior petroleum engineer, Stanolind Oil and Gas Co.

MICHIGAN

Northville—Lazar, Nicholas M. (M). Assistant professor of metallurgy, Wayne University.

MINNESOTA

Biwabik—Baker, Robert Allen. (C/S—S-J). Mining engineer, Pickands Mather & Co.

Duluth—Ferris, John A. (C/S—J-M). Mechanical engineer, Oliver Iron Mining Co.

Hibbing — Gleason, Michael, John. (M). Diamond drilling superintendent, E. J. Longyear Co.

MISSISSIPPI

Bonne Terre—Jewell, James Edwin. (R,C/S—JA-M). Geologist, St. Joseph Lead Co.

West Jackson — Herrald, Arthur Easton. (M). Division engineer, Schlumberger Well Surveying Corp.

MISSOURI

St. Louis—Desloge, Joseph John. (J). Student, Washington University. Hewitt, Lowell Cleland. (M). Vice-president and director of research, Laclede Christy Co. Lynott, William John. R,C/S—S-M). Instructor, geology department, Institute of Geophysical Technology, St. Louis University.

NEW JERSEY

Morristown—Ackerman, David Harton. (J). Geological assistant, Jones & Laughlin Steel Corp.

Plainfield — Gerwin, Benjamin Harrison. (A). Supervisor of refining operations, Kennecott Copper Corp.

Rahway — Leigh, Gilbert Merlin. (M). Research engineer, Metal and Thermit Corp.

NEW MEXICO

Carlsbad—Mills, Russell Holbrook. (M). Refinery superintendent, U. S. Potash Co.

Hanover—Huyett, Sterling Sutphen. (R,C/S—J-M). Mine chief, Empire Zinc Co.

NEW YORK

Brooklyn — Korman, Samuel. (M). Metallurgical chemist, Phelps Dodge Corp.

Larchmont — Dean, Robert Griffin.

(C/S—S-J). Junior engineer, Alcoa Mining Co.

Lyon Mountain—Zimmer, Paul William. (C/S—J-M). Geologist, Republic Steel Corp.

New York—Iliopoulos, George. (A). Vice-president, Silver and Barytes Ores Mining Co. Pappas, Hercules Cris. (C/S—S-J). Junior engineer, Alcoa Mining Co.

Scotia—Gaus, John Ernest. (C/S—S-J). Metallurgist, scientific program, General Electric Co.

Tahawus—Rogers, James John, Jr. (J). Geologist, titanium division, National Lead Co.

OHIO

Columbus—Elsner, Francis Robert. (J). Research engineer, Battelle Memorial Institute.

Shaker Heights—Folk, John Kenneth. (J). Laboratory metallurgist, American Steel and Wire Co.

OKLAHOMA

Ardmore—Millard, Frank Stutzman. (R,C/S—J-M). Chief engineer and district manager, Schlumberger Well Surveying Corp.

Blackwell — Page, Herbert Robert. (M). Assistant superintendent, Blackwell Zinc Co.

Picher—Stover, Curtis Edward. (R—M). Secretary, Tri-State Zinc and Lead Ore Producers Assn.

Tulsa—Lewis, Maurice, Jr. (C/S—S-J). Junior exploitation engineer, Shell Oil Co. Stocker, Stanley Harrison. (J). Petroleum engineer, Stanolind Oil and Gas Co. White, Foster Lee. (M). Captain, design and development officer, U. S. Air Force.

OREGON

Eugene — Baldwin, Ewart Merlin. (C/S—J-M). Assistant professor of geology, University of Oregon.

Portland—Jacobs, Charles W. F. (J). Ceramist, department of geology and mineral industries, State of Oregon. Matthews, Thomas Charles. (M). Spectroscopist, department of geology and mineral industries, State of Oregon. Miller, Roy Edmund. (M). President and general manager, Miller Products Co.

PENNSYLVANIA

Bethlehem—Aylward, Paul Thomas. (J). Research engineer, Bethlehem Steel Co. Dennison, Joseph Donahey, Jr. (J). Research engineer, Bethlehem Steel Co.

Greensburg—Reynolds, Rexford Vincent. (M). Development engineer, Kennametal, Inc.

Lehighton—Handwerk, Glenn Erwin. (J). Student engineer, Gulf Refining Co.

Pittsburgh—Floyd, Walter Ingram. (A). President, Duff-Norton Co. Goldman, Kenneth Marvin. (J). Research assistant, Carnegie Institute of Technology. Gulbransen, Earl Alfred. (M). Advisory engineer, Westinghouse Research Laboratories. Rowland, Dudley Hamilton. (M). Research associate, Carnegie-Illinois Steel Corp.

TENNESSEE

Chattanooga — Rivers, Curtis Fred. (M). General superintendent of coal mines, Tennessee Products and Chemical Corp.

Oak Ridge—Williams, Robin O'Dare. (J). Junior metallurgist, Oak Ridge National Laboratory.

Whitwell — Daffron, Herschel Andrew. (M). Mine superintendent, Tennessee Products and Chemical Corp.

TEXAS

Agua Dulce—Girand, Charles Francis. (R,C/S—S-M). Petroleum engineer and field superintendent, Rand Morgan.

Alice — Wilson, George Stanwood. (M). District petroleum engineer, Magnolia Petroleum Co.

Andrews—Sullivan, Richard Joseph. (C/S—S-J). Petroleum engineer, Stanolind Oil and Gas Co.

Bellaire — Robishaw, Earl Joseph. (M). Research engineer, A-1 Bit and Tool Co.

Bishop — May, Jonathan Thomas. (M). District superintendent, Chicago Corp.

College Station—Persons, John Verner. (R,C/S—S-M). Assistant professor, Agricultural and Mechanical College of Texas.

Corpus Christi—Brumby, Birto Ralston. (R,C/S—S-M). Production superintendent, Panhandle Production and Refining Co. Clark, James Muir. (M). Assistant superintendent, production and drilling, Chicago Corp. Johnson, Frank Aubrey. (M). Division superintendent, Halliburton Oil Well Cementing Co.

Dallas—Bixler, William Royce. (J). Petroleum engineer, Atlantic Refining Co. Tennant, Robert Hudson. (J). Petroleum geologist, De Golyer & MacNaughton. Walke, John Edwin. (M). Gas engineer, Sun Oil Co.

Houston — Beatty, Robert MacConnell. (M). Geologist, Trinity Petroleum Co. Bleakley, William Bruce. (C/S—S-J). Junior petroleum engineer, Stanolind Oil and Gas Co. Golden, Albert Courter. (M). Assistant to the vice-president, Pan American Production Co. Johnson, Robb C. (J). Engineer, Houston Oil Field Material Co. Main, Thomas Cole. (R,C/S—S-M). Chief process design engineer, Cons. Western Constructors, Inc. Wilson, Ernest Bradley, (M). Engineer and geologist, Sterling Oil and Refining Corp.

Levelland—McSpadden, Thomas Willard. (C/S—J-M). Head roustabout, Stanolind Oil and Gas Co.

Midland — Faris, Charles William. (M). Partner, Faris & Warren.

Odessa—Hardee, Peck, Jr. (R,C/S—S-J). District engineer, Texas Pacific Coal and Oil Co. Henley, Jack. (J). District geologist, Lane-Wells Co.

Overton—Thompson, Frederick Luther, Jr. (C/S—J-M). Petroleum engineer, Humble Oil and Refining Co.

Pittsburg—Kent, Leon Alfred. (J). Engineer-draftsman, Lone Star Steel Co.

Victoria—Binkley, John Frederick. (R,C/S — S-M). Petroleum engineer, Barnsdall Oil Co.

UTAH

Salt Lake City—White, John Blackwood, Jr. (C/S—J-M). Field engineer, Galigher Co.

WASHINGTON

Bellingham — Pascoe, James Henry. (M). Vice-president and general superintendent, Bellingham Coal Mines, Inc.

Metaline — Seerley, John Joseph. (C/S—S-J). Mine shift boss, Pend Orielle Mines and Metals Co.

Olympia—Stanton, William Layton. (M). Division geologist, Union Oil Co. of California.

Seattle—Dong, James Y. (C/S—S-J). Chemist, Bethlehem Pacific Coast Steel Co.

WEST VIRGINIA

Fairmont—Kingery, Donald Samuel. (R,C/S—J-M). Senior mining engineer, Bureau of Mines.

Fayetteville — Long, John Broadus. (M). President, Long Super Mine Car Co.

WYOMING

Laramie — Paine, William Rhodes. (C/S—S-J). Graduate school student, University of Wyoming.

ALASKA

Fairbanks—Proehl, Norman Preston. (C/S—J-M). Mining engineer, U. S. Smelting Refining and Mining Co.

ONTARIO

West Lorne—Evans, John Roy. (C/S—S-J). Trainee, Creole Petroleum Corp.

QUEBEC

Montreal — Robertson, Alexander Hugh. (M). Vice-president, Quebec Iron and Titanium Corp.

CHILE

Chuquicamata—Thurston, Frank Edward. (M). Junior engineer, Chile Exploration Co.

PERU

Cerro de Pasco — Shelton, Derek Clifton. (C/S—S-J). Assistant mine foreman, Cerro de Pasco Copper Corp.

ENGLAND

Birmingham — Swindells, Norman. (R,C/S—F-M). Chief metallurgist, McKechnie Bros., Ltd.

Warwickshire — Crowther, James. (M). Research metallurgist, James Booth & Co.

FRANCE

Mont-Saint-Martin — Guinard, Pierre Aimé. (M). Director of mines, Société des Aciéries de Longwy.

GREECE

Laurium — Conofagos, Constantin. (M). Chief metallurgist, Cie. Française des Mines de Laurium.

TANGANYIKA

Tabora — Landcastle, Ralph. (M). Inspector of mines, Government of Tanganyika.

CHINA

Hopeh—Lu, Ting-Tseh. (C/S—S-J). Training student, Kailan Mining Adm. Wang, Tsu-Na. (C/S—S-J). Training student, Kailan Mining Adm.

Peiping—Hu, Kao Chiang. (C/S—S-J). Research fellow, national bureau of mining and metallurgical research, Ministry of Economic Affairs.

VICTORIA

Melbourne—BARTH, HANS FRIEDRICH WILHELM. (M). Metallurgist, C. Huppery & Co.

Student Associates

Elected December 15, 1948

Robert K. Aaker	Univ. N. Dak.
John J. Abendschan	Colo. Sch. Mines
James L. Albright	Texas Mines & Met.
Howard A. Anderson, Jr.	Colo. Sch. Mines
Donald I. Andrews	Colo. Sch. Mines
Charles H. Armitage	Univ. Wis.
Donald G. Ashe	Colo. Sch. Mines
Herbert J. Ashe (Rein.)	Colo. Sch. Mines
Henry E. Aviles	Univ. Ariz.
Robert L. Ballard	Ohio State
John G. Barnes	Univ. N. Dak.
Virgil D. Basinger	Ohio State
John H. Bassarear	Colo. Sch. Mines
James R. Bassett	Yale Univ.
Kenneth M. Bearden	Texas Mines & Met.
William L. Beaton, Jr.	Texas Mines & Met.
Thomas E. Benedict	Okla. A&M
Jack B. Bennett	Colo. Sch. Mines
Roshan B. Bhappu	Colo. Sch. Mines
Irfan N. Bilen	Ohio State
James C. Birtell	Okla. A&M
Benson D. Blackie	Ohio State
Wayne F. Bohanan	Colo. Sch. Mines
Leo Borasio	Colo. Sch. Mines
Robert E. Bosco	Colo. Sch. Mines
Charles D. Bowling	W. Va. Univ.
Quinn G. Boyd	Texas Mines & Met.
Leo N. Bradley	Colo. Sch. Mines
Robert J. Brakey, Jr.	Okla. A&M
John A. Brandon	Colo. Sch. Mines
James E. Brazell	Okla. A&M
Robert E. Brooks	Univ. Okla.
Robert L. Brown	Univ. Ill.
Robert A. Burney	Ohio State
Robert L. Burns	S. Dak. Sch. Mines
Dewey J. Bushaw	Univ. N. Dak.
Daniel W. Butner, Jr.	Colo. Sch. Mines
Franklin W. Butterfield	Univ. Nev.
Tom G. Calhoun	Texas A&M
Samuel H. Caran	Ohio State
Melvin Carlson	Colo. Sch. Mines
Arduino Castrale	Mo. Mines & Met.
Clifford H. Chandler	Ohio State
Wei K. Chang	Mo. Mines & Met.
Donald D. Christofferson	Univ. N. Dak.
Robert K. Christofferson	Okla. A&M
Donald G. Christy	Univ. N. Dak.
Richard J. Clifford	Ohio State
Robert K. Collins	S. Dak. Sch. Mines
Dowd L. Cooper	Oreg. State Coll.
Earl J. Cox	S. Dak. Sch. Mines
Bob C. Crittendon	Okla. A&M
William C. Cross	Texas Mines & Met.
John T. Cullom	Mo. Mines & Met.
Donald A. Damkroger	Univ. Nev.
Wesley F. Danielson	Univ. Minn.
Raymond E. Daugherty	Mo. Mines & Met.
William D. DeGeer, Jr.	Univ. Okla.
Karl H. DelPorte	Mo. Mines & Met.
Charles F. Deuel	Colo. Sch. Mines
Tony J. DiPrimo	Mo. Mines & Met.
Russell P. DiSano	Queens Univ.
Billy F. Dittman	Colo. Sch. Mines
Danford J. Dodds	Colo. Sch. Mines
Jack H. Dressel	Colo. Sch. Mines
Mukunda B. Dutt	Ohio State
Honorato S. Echavez (Rein.)	Univ. Kans.
A. B. Echols, Jr.	Okla. A&M
Frederick W. Elton	Colo. Sch. Mines
Edward W. Ely	Colo. Sch. Mines
Francis P. Embree	Columbia Univ.
Homer C. English	Univ. Okla.
Eric F. Engbrecht	Univ. N. Dak.
John W. Felmet, Jr.	Ohio State
George H. Fentress	Colo. Sch. Mines
Lewis I. Field, Jr.	Carnegie Inst. Tech.
George E. Fish	Mo. Mines & Met.
Robert B. Fisher	Texas Mines & Met.
Marcellus M. Fitzwater, Jr.	W. Va. Univ.
Ralph C. Flow	S. Dak. Sch. Mines
Frank A. Foley	Colo. Sch. Mines
William R. Foley	Carnegie Inst. Tech.
Robert L. Fossi	Mo. Mines & Met.
Arthur L. Franks	Mo. Mines & Met.
Marshall M. Frazier	Okla. A&M
Reese L. Freeland, Jr.	Univ. S. Calif.
E. L. Frey, Jr.	Univ. Ill.
John E. Frost	Stanford Univ.
Russell J. Gamberg	S. Dak. Sch. Mines
Larry A. Garfield	Colo. Sch. Mines
Lowell W. Gibbs	Univ. Minn.
Ernest R. Glabau	Lafayette Coll.
William A. Gloe	Univ. Wis.
Glenn R. Gobble	Ohio State
James H. Goble	Okla. A&M
Jesse H. Gravely	W. Va. Univ.
Walter V. Green	Univ. Wis.
Charles A. Greenlee	Ohio State
Thomas L. Gregory	Iowa State
Jack S. Griggs	Univ. Okla.
Max L. Grimshaw	Ill. Inst. Tech.
Marius P. Gronbeck	Mo. Mines & Met.
Frank Haban	Univ. Mich.
Glenn G. Hager	Okla. A&M
Edwin Halpern	Columbia Univ.
John N. Hansen	Univ. Wis.
Glenn M. Hanson	S. Dak. Sch. Mines
John S. Hanson	Univ. Wis.
Fredric H. Harf	Univ. Mich.
Robert A. L. Harms	Okla. A&M
Wayne D. Hart	Mo. Mines & Met.
Robert H. Haubrich	Univ. Wis.
Richard G. Heath	Ohio State
Robert E. Hebert	Mo. Mines & Met.
John J. Henderson	Texas Mines & Met.
George W. Herbst	Univ. Minn.
Leonard F. Herzog, II	MIT
Albert J. Higgins	Mo. Mines & Met.
Gerald Hoffman	Colo. Sch. Mines
Clement Hofmann	Colo. Sch. Mines
Thomas A. Holmes	Mo. Mines & Met.
John J. Hooten	Okla. A&M
Marcus Hoppes	Univ. Kans.
Paul S. Hopson	Okla. A&M
William E. Horst	Mo. Mines & Met.
David M. House	Okla. A&M
Harold B. Houston	Okla. A&M
Chi-mei Hsiao	Mo. Mines & Met.
Walter E. Hyde	Okla. A&M
Robert N. Imhoff	Ohio State
Lytton F. Ivanhoe, Jr. (C/S—J-S)	Stanford Univ.
John W. Jackson	Okla. A&M
Crawford E. Jacobsen	Univ. Calif.
Edward F. Jacobson, Jr.	S. Dak. Sch. Mines
Arthur J. Jersin	Colo. Sch. Mines
Donald A. Jess	Univ. Idaho
Howard R. Johnson	Colo. Sch. Mines
John E. Kaites	W. Va. Univ.
Leonard F. Kane	Mo. Mines & Met.
Elias L. Kapernaros	Mo. Mines & Met.
William B. Kays, Jr.	Colo. Sch. Mines
Peter O. Kirchhoff	Univ. Wis.
Norman E. Klarquist	Univ. Minn.
John W. Knack	Univ. Wis.
Michael C. Kopchak	Ill. Inst. Tech.
Walter A. Kramer	Mo. Mines & Met.
Virgil W. Krutsinger	Univ. Kans.
William C. Kunkler, Jr.	Yale Univ.
Charles O. Kunz	Mo. Mines & Met.
Ralph W. LaCrone, Jr.	Okla. A&M
Victor A. LaFave, Jr.	Texas Mines & Met.
Leslie L. Lamb	Okla. A&M
John Lamprecht	Univ. Minn.
William G. Lang	Univ. Ill.
Merritt E. Langston	Mo. Mines & Met.
Valdemar F. Larson	Univ. Nev.
Khwaja A. Latif	Colo. Sch. Mines
Edmond H. Leavey, Jr.	Colo. Sch. Mines
Frank J. Leedom	Univ. Wis.
Herbert L. Leonard, Jr.	Ohio State
Robert D. Lindau	Texas Mines & Met.
Colin Liu	Colo. Sch. Mines
You Chao Liu	Yale Univ.
Robert F. Lutz	Univ. Minn.
John E. Maddox	Okla. A&M
Clifford A. Mark	Colo. Sch. Mines
Richard W. Martini	Univ. Wis.
William E. B. Mason	Queen's Univ.
Robert R. McCabe	Texas Mines & Met.
Thomas J. McCroden	Stanford Univ.
Ross M. McDonald	Colo. Sch. Mines
Elwin D. McKnight	Texas A&M
John A. Michelson	Ohio State
John R. Mihalisin	Yale Univ.
Roy G. Miles	Mo. Mines & Met.
Daniel N. Miller, Jr.	Mo. Mines & Met.
Melbourne W. Miller	Colo. Sch. Mines
Ralph W. Minga	Univ. Ala.
Charles R. Mitchell	Univ. Ill.
Roy B. Moffitt	Univ. Ala.
William R. Monroe, Jr.	Mo. Mines & Met.
Ted R. Moore	Okla. A&M
Frederick P. Morawski	Yale Univ.
Fred R. Mulker	Univ. Calif.
Arthur W. Mullendore	Univ. Wis.
John W. Murchison	Texas A&M
James D. Murdoch, Jr.	Univ. Okla.
Jerome G. Murkve	Univ. Wis.
Edward E. Murray	Wash. State
Carl J. Muser	Ohio State
John W. Musser	Lafayette Coll.
Bert Myatt, Jr.	Okla. A&M
Denis A. Nankivell	Yale Univ.
John B. Neuenkirchen	Adelaide Univ.
Thorsten L. Neyman	Univ. Minn.
Richard C. O'Brien	Mo. Mines & Met.
William H. Osmus	Univ. Calif.
Harry B. Owens, Jr.	Okla. A&M
Robert L. Owens	Mo. Mines & Met.
Robert L. Owens	Lafayette Coll.
Malcolm F. Parkman	Wash. State
William G. Paulsell	Mo. Mines & Met.
George T. Peart	Colo. Sch. Mines
John A. Pederson	Univ. Wis.
Emil Perout	Univ. Cinn.
John H. Peterson	Univ. Wis.
William R. Peterson	Ohio State
Marvin N. Peyser	CCNY
Richard P. Phillips	Stanford Univ.
Francis L. Pierson	Texas Mines & Met.
Max D. Pierson	Texas Mines & Met.
Philip C. Pierson	Ohio State
Richard A. Pinto	Yale Univ.
Charles H. Pitt	Univ. Wis.
Ray N. Plummer	Okla. A&M
Andrew Pocalyko	Yale Univ.
James C. Porterfield	Okla. A&M
Voluntine T. Potter	Yale Univ.
Charles E. Price, Jr.	Univ. Ala.
Harry Ptasynski	Stanford Univ.
J. R. Ramsey	Mo. Mines & Met.
Robert J. Rankin	Univ. Nev.
James H. Ratchen	Ohio State
Raymond W. Reed	Mo. Mines & Met.
Robert H. Regan	Mo. Mines & Met.
Jay L. Reiss	RPI
Stanley F. Reiter	Yale Univ.
George R. Remarcke	Univ. Minn.
William F. Ricketts, Jr.	Mo. Mines & Met.
Harvey V. Risien	Texas A&M
Gilman C. Ritter (Rein.)	Univ. N. Dak.
Harry L. Rose	Mo. Mines & Met.
John R. Ross	Colo. Sch. Mines
Kermit G. Rowley	Mo. Mines & Met.
Jarnes H. Roy	Univ. Idaho
Paul E. Ruff	Ohio State
Fred E. Rugg	Colo. Sch. Mines
John R. Salvaggi	Mo. Mines & Met.
William H. Santschi	Ohio State
Grover C. Sartin, Jr.	Okla. A&M
Hugo P. Saviola	Mo. Mines & Met.
Richard D. Sawyer	Univ. S. Calif.
Warren B. Schipper	S. Dak. Sch. Mines
Jerome D. Schlottmann	Texas Mines & Met.
William F. Schmollinger	Yale Univ.
William A. Schrader, Jr.	Univ. Wis.
David B. Schulz	Colo. Sch. Mines
Eugene A. Scussel	Texas Mines & Met.
Henry J. Scussel	Texas Mines & Met.
John Sedor, Jr.	Ohio State
Berman J. Shafer	Ohio State
Marlow E. Sharpe	Colo. Sch. Mines
William M. Shepard	Mo. Mines & Met.
James C. Shepherd	Univ. Kans.
Henry M. Shillinglaw	Univ. Wis.
Merton I. Signer, Jr.	Colo. Sch. Mines
James N. Siltanen	Ill. Inst. Tech.
Charles C. Simpson, Jr.	Univ. Ala.
Thomas G. Sinclair	Texas A&M
Walter J. Smit	Texas Mines & Met.
Arthur C. Smith	Univ. Ariz.
Bertram L. Smith, Jr.	S. Meth. Univ.
Jake R. Smith	Colo. Sch. Mines
John G. Smith	Colo. Sch. Mines
Lowell T. Smith	Mo. Mines & Met.
Oziel L. Smith, Jr.	Okla. A&M
Stuart A. Smith	Yale Univ.
Verne L. Snow	Okla. A&M
Gerald W. Spotts	Okla. A&M
James T. Stanley	Univ. Ill.
Walter L. Steinhilber	CCNY
Norman C. Stevenson	Okla. Inst. Tech.
Raymond M. Stewart	Colo. Sch. Mines
Bobby G. Stoops	Okla. A&M
Robert R. Strange	Ohio State
Erwin J. Strecker	Univ. N. Dak.
James R. Stringham	Colo. Sch. Mines
Hung-Shung Sung	Ohio State
Horace Sutcliffe, Jr.	Univ. Ala.
Theodore M. Swanson	Univ. Minn.
Charles A. Tallard	Univ. Minn.
Yeshwant P. Telang	Univ. Mich.
Paul J. Theusen	Mo. Mines & Met.
Mitat Y. Tolgay	Mo. Mines & Met.
Emery M. Tower, Jr.	Okla. A&M
John F. Townsend	Okla. A&M
James W. Tracey	Okla. A&M
Jack K. Trotter	Mo. Mines & Met.
John Turyn, Jr.	W. Va. Univ.
Robert VanNostrand (Rein.)	Mo. Mines & Met.
Ray J. VanThyne	Ill. Inst. Tech.
Oscar M. Villareal	Texas Mines & Met.
Herbert N. Wade	Texas A&M
Edward Walther, Jr.	Univ. Ala.
Norman F. Warren	Univ. Nev.
Justin E. Weatherly, Jr.	Texas A&M
Keith T. Webb	S. Meth. Univ.
Robert I. Weiner	RPI
Franklin J. Weishaupl	Colo. Sch. Mines
Herman E. Wendy	Texas A&M
Samuel W. West	Okla. A&M
Robert D. Whitmer	Mo. Mines & Met.
Olen H. Whitmire	Texas Mines & Met.
Alexander Wiegel	Ill. Inst. Tech.
Donald E. Williams	Ohio State
Gerald M. Wilson	Mo. Mines & Met.
Harold S. Winston	Univ. Minn.
John S. Winston	Mo. Mines & Met.
John C. Wright	Ohio State
John H. Wyatt	Colo. Sch. Mines
Arthur H. Yarberry	Colo. Sch. Mines
Michael Yole	Queen's Univ.

The Morenci Smelter of Phelps Dodge Corporation at Morenci, Arizona

L. L. McDANIEL,* Member AIME

Copper smelters of various kinds have operated in the Morenci district since 1872, but all have been abandoned with the exception of the present Morenci Smelter of Phelps Dodge Corporation, which was completed in 1942.

During the five-year period starting in 1937, the Morenci ore body was prepared for open pit mining, pilot mill test work was carried out, and a complete reduction works, of which the Smelter is a part, was designed and erected. Actual construction work on the Morenci Smelter was started in the fall of 1940, and warming up of the units began on April 1, 1942. Charging of the reverberatory furnaces commenced on April 18, 1942, and the first anode copper was produced on April 26, 1942.

The smelter was originally designed to handle the production of the Morenci Concentrator on a 25,000 ton per day program, but by the time the smelter was in operation, plans were already underway to increase the smelter capacity to handle the production of the concentrator which was being enlarged to 45,000 tons a day capacity as a war-time necessity. This extension to the smelter was completed and the new units were put in operation toward the beginning of 1944.

The original smelter consisted of a smelter crushing plant, bedding plant, two direct-smelting reverberatory furnaces with two waste-heat boilers on each furnace, three converters, an anode department, a stack, and all of the usual accessory smelting equipment. The extension consisted of increasing the bedding plant from three to five beds, the reverberatory department from two to four furnaces, and from four to eight waste-heat boilers, and the converter department from three to six converters. A third converter aisle crane was added and additions were made to the flue systems and conveyor systems throughout the smelter; but no change was made in the smelter crushing plant or the anode department, and the same stack was used for all additional Smelter units. A blister casting machine was installed at that time in the south end of the converter aisle to handle excess and emergency production above the capacity of the anode department and in 1947 a converter aisle skull breaker and a lime burning plant were added as the final units for a complete plant.

The choice of direct smelting over calcine smelting for the Morenci Smelter was made after careful study by members of the Western organization of Phelps Dodge Corporation and after test runs on direct smelting of Morenci concentrate had been made at the Douglas Smelter of Phelps Dodge Corporation. The Morenci furnace charge is made up of comparatively high grade concentrate with no ores of smelting grade available and with only flux, a small amount of copper precipitate and the usual amount of smelter secondaries to be smelted with the concentrate. The simplicity of direct smelting for this charge and the large amount of waste-heat steam available from direct smelting operations were factors influencing the decision to adopt direct smelting for Morenci. The design of the Morenci Smelter and the type of units selected followed best experience at the Douglas Smelter of Phelps Dodge Corporation.

A description of the original smelter before operations started was given in an article in the May 1942 issue of *Mining and Metallurgy*. The purpose of the present article is to describe the enlarged Morenci Smelter, with a discussion of metallurgy and operating practice and to show tabulations of operating and metallurgical results obtained. Because of beginning operations during the early years of World War II, many problems caused by labor shortage were encountered, but no major difficulties developed in starting the new plant. However, because of labor shortage, full scale Smelter production was not reached until the fall of 1946.

Fig 1 shows a general plan of the Morenci Reduction Works. The arrangement of the smelter equipment is shown in Fig 2, a sectional view of the smelter is shown in Fig 3, and the smelter flow sheet is shown in Fig 4.

Metallurgy

The metallurgy of direct smelting, being more or less fixed by the character of the charge, is not subject to the control available in calcine smelting. Slags may be modified by the addition of suitable fluxes, but the grade of the matte is determined almost entirely by the iron:copper ratio of the concentrate.

The direct smelting operation involves distributing the wet concentrate along the sidewalls and in the bath of a reverberatory furnace by means of some suitable feeding device and raising the temperature of the charge so that first the moisture is driven off, then the first-atom sulphur is eliminated, and finally the sulphide portion of the charge melts and runs into the bath, carrying with it the non-sulphide portion which has been partially fluxed to form a suitable slag. The fusion of the non-sulphide portion is completed by contact with the irony converter slag which is regularly being poured into the reverberatory furnace. The smelting rate of the charge is influenced by the mineralogical composition of the sulphide portion of the concentrate and by the composition and amount of the non-sulphide portion including the fluxes added.

The copper in Morenci concentrate is chiefly in the form of chalcocite, intimately associated with pyrite, and non-sulphide content is very low so that

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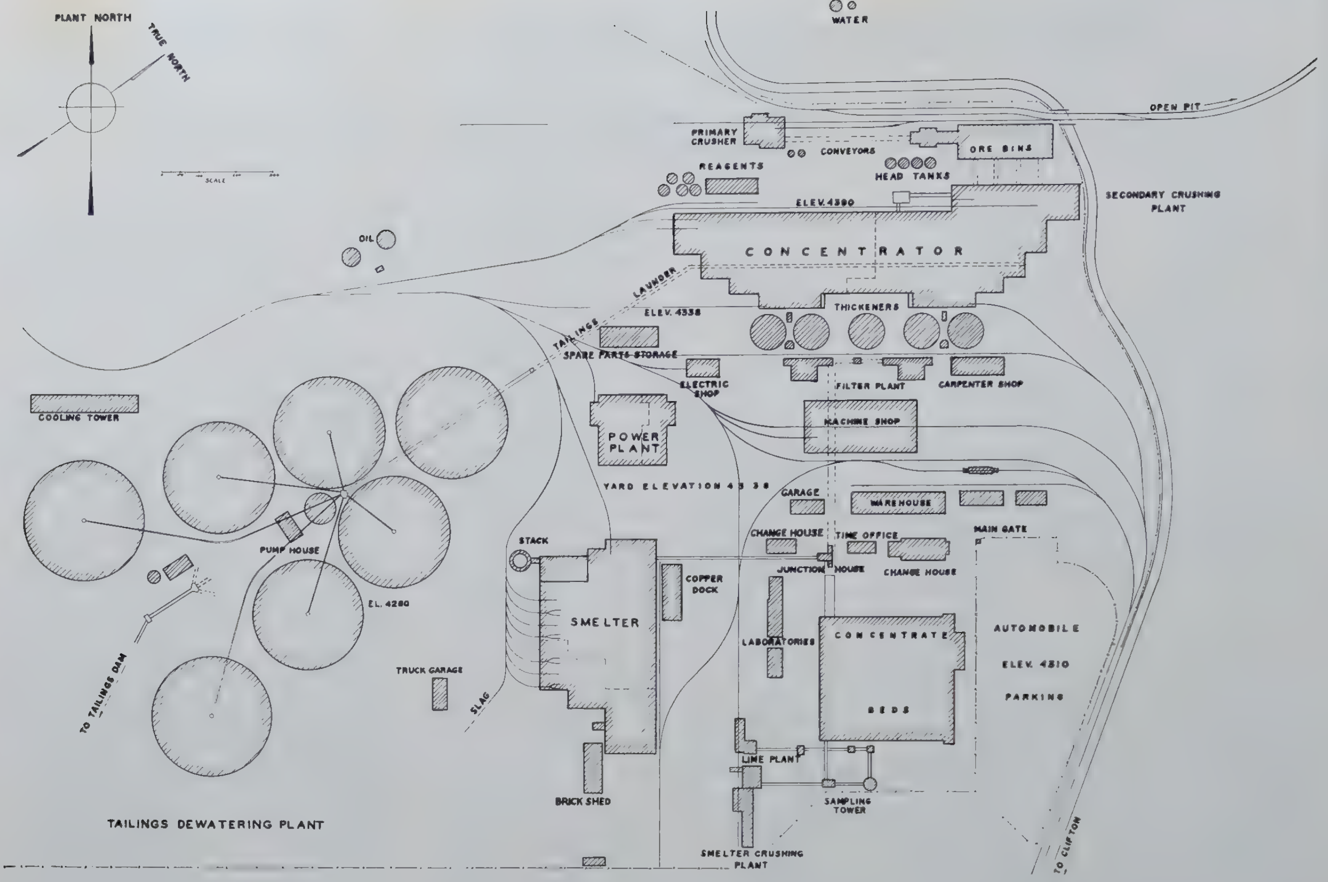

FIG 1—General plan of Morenci reduction works.

the main problem of the smelter is in fluxing and eliminating iron. The copper content of the Morenci concentrate increased appreciably, and the iron content decreased during the first few years of operation. Smelter metallurgy improved correspondingly as the iron burden was lessened and the converters were relieved of part of their work. The concentrate is graded upward 7.0 to 8.0 units of copper in forming matte, the amount being influenced somewhat by the quantity of precipitate on the charge.

There is no metal bearing siliceous flux readily available in the Morenci district and ore from the Open Pit mining operation is too high in alumina to be used alone. It has been necessary therefore, to mine a barren quartzite for use in modifying furnace slags. This is also used in adjusting the silica: alumina ratio of the Pit ore used for converter flux to prevent the formation of excessive amounts of magnetite in converter slags. Limerock is used to flux the non-sulphide content of the concentrate, and at times, additional limerock and quartzite are added to the bedded concentrate to reduce the moisture content of the furnace feed.

The make-up of the furnace charge is usually quite uniform although at times other material has been smelted. In 1943 and 1944 a large amount of clean-up material from an old smelter in the district was crushed and smelted in the reverberatory furnaces, and during early operations at the smelter a large quantity of reverts accumulated in the converter aisle which eventually were crushed and smelted with the reverberatory furnace charge. At the present time most of the converter reverts are smelted directly in the converters and any excess is crushed and added to the converter flux to modify the high silica content resulting from the use of barren quartzite. Foul slag from the reverberatory furnaces is also crushed and added to the converter flux for this purpose. Crushing of reverts and foul slag is done simultaneously with the barren quartzite to insure a good mixture.

The dry weight of concentrate received at the smelter is calculated by the concentrator from actual weightometer weights of feed to the ball mills and assays of automatic samples of feed, tailings and concentrate. This method has been very reliable over a considerable period of time. The moisture content of the concentrate is determined by sampling as the concentrate leaves the filter plant.

Smelter slag, stack and mechanical losses are shown in Table 1. Stack loss tests are made regularly and reverberatory slags are sampled at the furnace

Table 1 . . . Losses Expressed as Percent of Input

	Copper			Silver			Gold		
	Slag	Stack and Mechanical	Total	Slag	Stack and Mechanical	Total	Slag	Stack and Mechanical	Total
1942	1.41	0.52	1.93	1.74	0.51	2.25	2.12	0.01	2.13
1943	1.50	0.69	2.19	1.65	2.71	4.36	2.87	0.55	3.42
1944	1.42	0.81	2.23	1.28	0.73	2.01	1.38	0.45*	0.93
1945	1.22	0.62	1.84	1.09	1.38	2.47	1.40	0.74*	0.66
1946	1.12	0.94	2.06	0.99	0.89	1.88	1.03	0.30*	0.73
1947	1.20	0.83	2.03	1.02	1.01	2.03	1.25	0.70*	0.55

* Gain

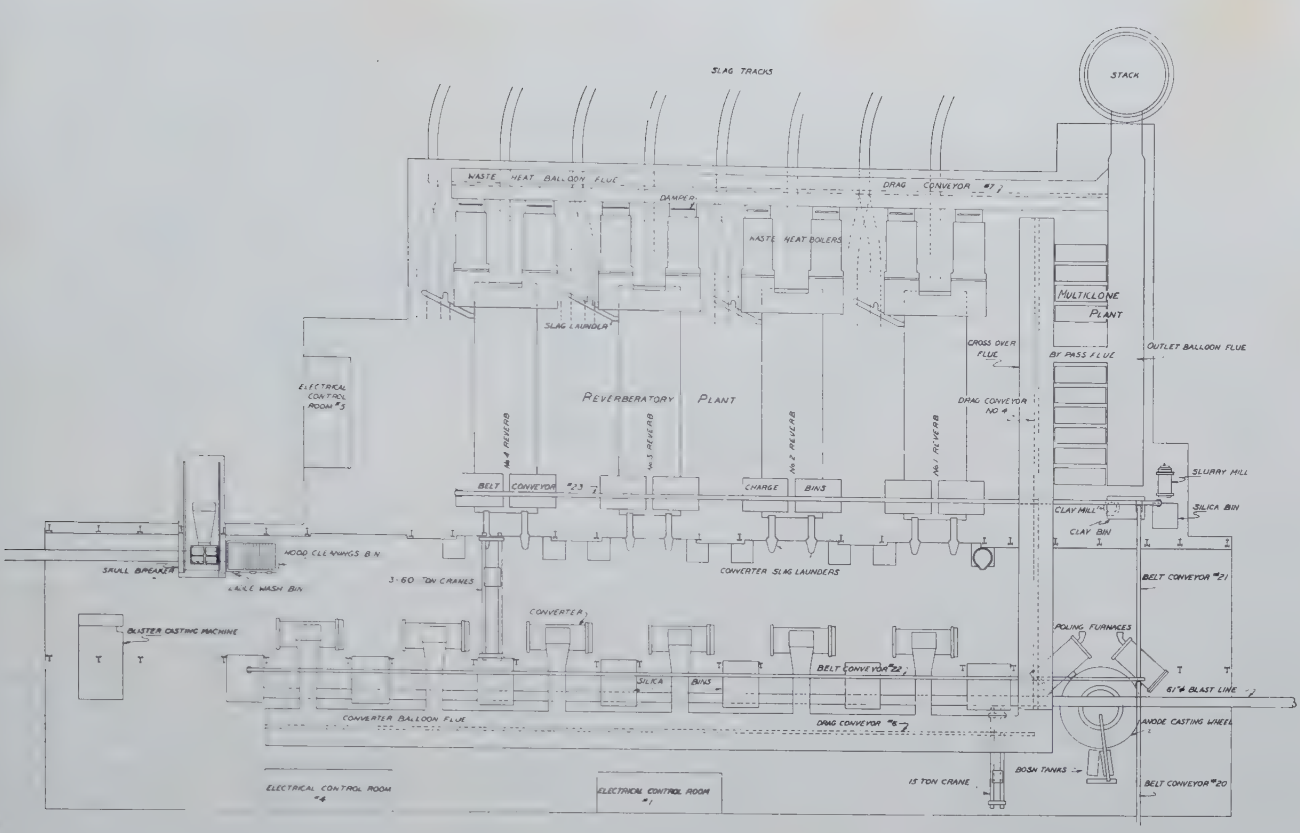

FIG 2—Arrangement of smelter equipment.

and on the dump. Anode copper is weighed and sampled at the refinery for final settlement.

Results have shown that direct smelting of Morenci concentrate has proved successful with a concentrate grade above 25.0 pct copper and an iron:copper ratio of about 1.00, and that smelter equipment and arrangement have been satisfactory. Production figures for the total plant are shown in Table 2. In all tabulations in this paper figures for 1946 are based on 8.4839 months operating time because of a general strike in the industry which caused a shut-down that year.

Smelter Crushing Plant and Lime Burning Plant

The smelter crushing plant was designed to crush Pit ore and siliceous ore for converter flux and limerock and siliceous ore for reverberatory flux, as well as smelter reverts and miscellaneous material required in smelter operations. The crushing plant was also designed to crush limerock for a lime burning plant which is operated by the smelter organization to produce burned lime for the Concentrator.

In order to eliminate crushing of large sized material from open pit shovel mining operations, Pit ore crushed to ¾ in. is drawn from the fine ore bins at the concentrator into 40 yd side dump railroad cars and hauled to the smelter crushing plant and then conveyed to converter flux bins in the bedding plant without further crushings. Barren quartzite is mined in a quarry near the Reduction Works and trucked to the smelter crushing plant. Truck haulage is to be replaced by rail haulage at a later date. Limerock is mined in a quarry near the Open Pit Mine, trucked for a short distance, and loaded into side dump railroad cars for haulage to the smelter crushing plant.

The 100-ton receiving bin in the smelter crushing plant is served by railroad cars or trucks and the material is fed by a 48-in. pan feeder directly into a 36- × 48-in. jaw crusher. The 4-in. product of the jaw crusher passes over a 5- × 10-ft mechanically vibrated rod deck screen with 1⅙-in. opening, the oversize feeding directly into a 7-ft standard cone crusher with 1¼-in. setting. This loose setting is required because of crushing smelter reverts containing metallic copper. The combined product of the 7-ft standard crusher and screen passes over another 5- × 10-ft rod deck screen with ¼-in. opening, the oversize falling into a 4-ft shorthead cone crusher which is in closed circuit with the screen.

In the case of Pit ore and siliceous ore used for converter flux the material by-passes the 4-ft shorthead crusher and goes directly to the 5,000 ton storage bins at the end of the bedding plant. Limerock for flux and other material which is crushed to ¼ in. in the shorthead crusher may be delivered either to sections of the storage bins or directly to the beds. The material leaving the crushing plant is sampled by an automatic sampler in a sample tower, which takes a 10 pct cut. The material so far sampled has been barren flux and

Table 2 . . . Operating Data Total Plant

	Average per Month Tons N.M.B.M. Treated	Pct Copper Input N.M.B.M.	Actual Production Average Month Salable Copper	Power Used Kw Hr Per Ton N.M.B.M.
1942	29,981	18.02	10,439,844	57.90
1943	36,948	18.58	13,276,948	62.26
1944	35,194	21.31	14,702,658	82.68
1945	32,579	24.00	15,335,529	75.22
1946	41,559	24.90	20,204,926	68.41
1947	51,906	24.29	24,708,705	64.77

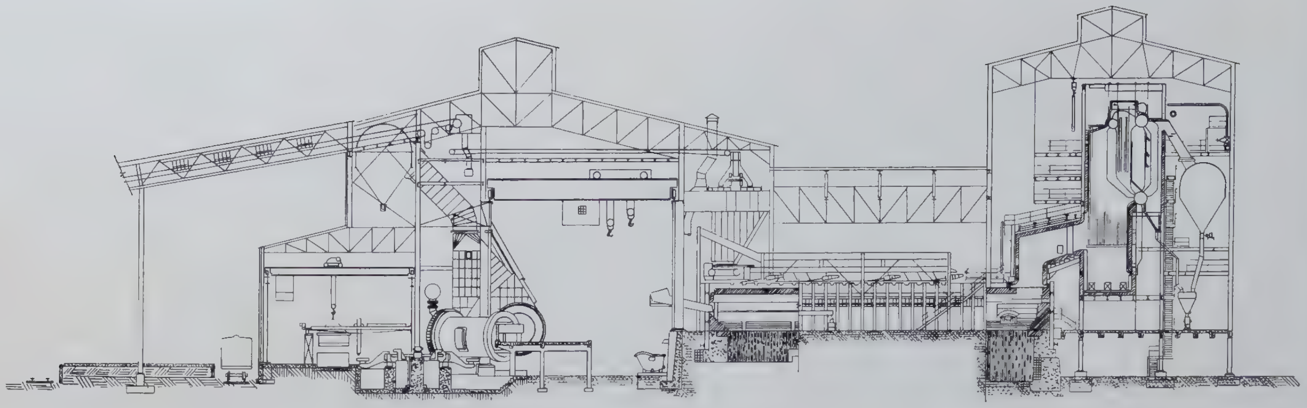

FIG 3—Sectional view of smelter.

no information has been obtained on operation of the sampling equipment.

Limerock for the lime burning kiln by-passes the shorthead crusher and is delivered to a 5- × 10-ft rod deck screen with ¼-in. opening in the sample tower, from which the undersize goes to the bedding plant storage bins and the oversize goes to the lime burning plant 1,000-ton capacity storage bin. Limerock from this storage bin is delivered by belt conveyor to the 275-ft rotary lime burning kiln which is fired with natural gas and produces 100 tons of burned lime per day.

A lime hydrating plant using a ball mill and classifier for preparation of milk of lime for the Concentrator adjoins the smelter crushing plant and receives burned lime from the 900 ton storage bin at the discharge end of the lime kiln. Milk of lime is pumped to the Concentrator through a 10-in. pipe.

The smelter crushing plant, sample tower, lime plant and storage bins are provided with dust control systems using wet collectors for the exhaust from the fans.

Bedding and Reclaiming Plant

The bedding plant serves a two-fold purpose: (1) It smooths out daily variations in concentrate composition so that furnace metallurgy and matte grade will be more uniform and, (2) it provides storage capacity to take care of interruptions to operations in either the Smelter or the Concentrator.

There are five beds, completely enclosed to prevent wind losses. The beds are 66 ft wide and 300 ft long with an effective bedding area of 50 × 250 ft which gives a capacity of 5,000 tons of concentrate each. Concentrate from the filter plant is delivered by two conveyor belts in parallel onto cross-conveyors over each of the beds where the concentrate is automatically distributed from one end of the bed to the other by motor driven tripper cars. After a bed has been completed and analysis made, the proper amount of limerock and siliceous ore flux is removed from the storage bins and diverted by means of a shuttle conveyor in the junction house, which is a distribution point, to one of the conveyors from the filter plant. The flux is delivered from this conveyor to the overhead conveyor above the bed and distributed over the concentrate on the bed. Flux may also be diverted directly from the smelter crushing plant to the cross conveyors over the beds. A bin in the junction house is provided with a belt feeder to handle copper precipitate and cleanup material from the smelter and feed it onto the concentrate conveyor delivering to the beds. Flue dust from a pug mill is also added to this conveyor in the junction house.

The final bedded mixture of concentrate and flux is removed by a reclaiming machine working into one end of a bed and plowing across the face and delivering the mixture onto a belt conveyor in a trench along the side of the bed. The reclaiming rate is about 150 tons per hr. There are two reclaiming machines which can be moved to any bed by means of a transfer car. This method of bedding and reclaiming furnace charge provides great flexibility in fluxing the charge and results in a very nearly perfect mixture of the charge for the furnaces.

The furnace charge, which is dropped on the trench belt by the reclaiming machine, is delivered through the junction house onto an inclined belt conveyor which transports the material across the converter aisle to a cross conveyor and then to two 265-ton bins above each reverberatory furnace. Small sections of these bins are also used for siliceous material for fettling. The same conveyor belt system is used to remove converter flux from the storage bins and deliver it to 250-ton bins above each converter. Clay for a mud mill and quartz for a slurry mill are also delivered to bins on the reverberatory floor by this belt system.

Twenty-inch conveyor belts are used on all overhead receiving conveyors and 24-in. conveyor belts are used on the reclaiming system delivering material from the beds to the smelter. All belt conveyors are provided with dust collecting systems at transfer points in the junction house and at the top of the smelter building. In addition, the conveyor gallery above the converter flux bins is kept under slight pressure by a ventilating system delivering 75,000 cfm of fresh air, which keeps the gallery free from smoke and reduces temperature for the comfort of workmen and protection of the conveyor belting. A similar installation in the conveyor gallery over the reverberatory furnace bins discharges 100,000 cfm of fresh air.

Reverberatory Furnaces

The four direct-smelting reverberatory furnaces are located on a block of unexcavated ground 15 ft above the surrounding yard level. Furnace foundations are formed of heavy, re-inforced concrete in a monolithic band around the furnace. Concrete beams were placed between the furnaces, which are on 70-ft centers, and the outer walls of the foundations on No. 1 and No. 4 furnaces were carried downward an additional 8 ft to prevent bending of the longitudinal sections by expansion pressures.

After the concrete foundations for the furnaces were poured and the rods for the end steel bindings were in place slag bottoms were poured in the furnaces to seal the conglomerate subsoil and to anchor the end steel bindings. Slag for the first two furnace bottoms was melted in a small natural-gas fired reverberatory furnace located between the two furnace foundations. An abandoned reverberatory furnace at an old smelter in the district was dismantled and the brick and steel were used to build the 14 × 50 ft slag melting furnace. Crushed blast furnace slag was obtained from a slag dump from previous operations in the Morenci District and the slag was hauled to the furnace site in trucks and charged into the small furnace with a grab bucket on the boom of a motor crane. Slag was tapped in about 30-ton lots into launders leading into the furnace bottoms. The depth of slag poured in the end sections of the bottoms was 8 ft and in the middle sections 4 ft. The slag remained partly liquid underneath the crust between pours and the final block of slag was dense and relatively free from cracks. About 1200 tons of slag was poured in each bottom. Slag for the bottoms of the last two reverberatory furnaces constructed, No. 3 and No. 4, was run directly from No. 2 reverberatory furnace through launders to the new furnace bottoms.

An attempt was made to fuse in the final furnace bottoms for the first two furnaces with 24 in. of crushed silica at the time the furnaces were started up. However, as soon as charging of the furnaces began, the silica bottoms in both furnaces came up and were lost. The bottoms floated shortly after charging was started and as soon as sufficient matte had accumulated to penetrate beneath the bottom and force it up.

The loss of the silica bottoms occasioned no serious delay to operation, and it developed that the furnaces operated very satisfactorily without the silica bottoms and with a deep bath of matte resting directly upon the original slag bottom that was poured into the furnace at the time the furnaces were constructed. There was no noticeable effect on the furnace foundations from the deep bath of matte, and the bath of matte actually aided in smelting the charge. It was therefore decided to build the two new furnaces, No. 3 and No. 4, without silica bottoms and with the poured slag bottoms at approximately the same elevation as in the first furnaces, that is, about 24 in. below the matte tap holes. This was done and these slag bottoms in all furnaces have been very successful. However, the deep bath of matte below the tap hole has not proved advantageous over a period of time because of lack of circulation of the matte. The bottom soon fills up with magnetite to the elevation of the tap holes and it is therefore the present practice when digging out a furnace to leave the bottom at an elevation only a few inches below the tap hole.

Structural details of the furnaces are shown in Fig 5. The furnaces measure 31 ft 3 in. × 110 ft 0 in. from face to face of buckstays and 25 ft 6 in. × 102 ft 6 in. inside the brickwork at the normal slag line. All steel bindings are of exceptionally heavy construction.

The furnace arches, sidewalls and endwalls are made of silica brick. The bridgewall and front walls are faced with chemically bonded magnesite brick and there is a band of magnesite brick completely around the furnace walls, constituting a crucible below the metal line. The furnace uptakes and cross-overs to the boilers are largely of suspended brick construction, with high alumina fire brick in the walls and magnesite brick in the arches. Dampers of light weight insulating brick and alloy steel construction are suspended above the cross-overs for use between the furnace and the boiler.

The 20 in. silica brick arches of the reverberatory furnaces have shown

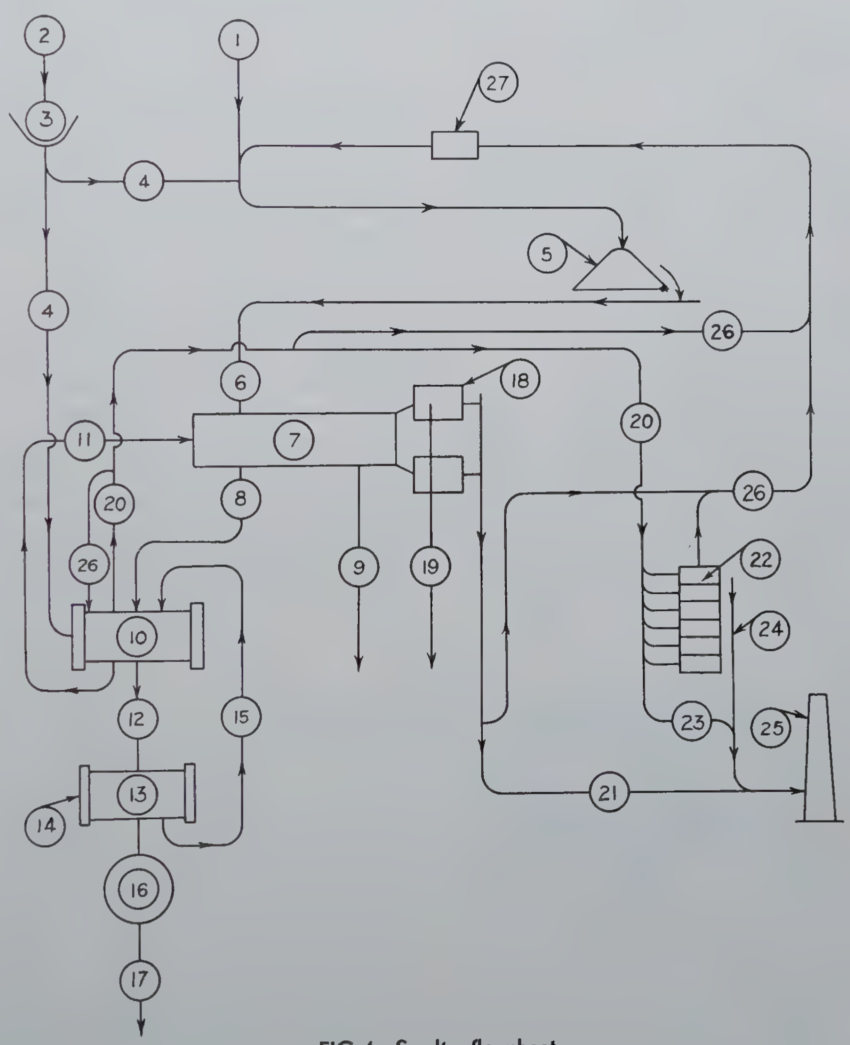

FIG 4—Smelter flowsheet.

1	Concentrate from filter plant
2	Flux from smelter crushing plant
3	Flux storage bins
4	Flux to converters and bedding plant
5	Bedding plant (5 beds, 5000 tons each)
6	Mixed charge to reverberatories
7	Reverberatory furnaces (4 furnaces, 25 ft 6 in. by 102 ft. 6 in.)
8	Matte to converters
9	Slag to dump
10	Converters (6 converters, 13 by 30 ft)
11	Converter slag to reverberatories
12	Molten blister to anode furnaces
13	Anode furnaces (2 furnaces, 13 by 25 ft)
14	Poles
15	Slag to converters
16	Casting wheel (40 ft diam)
17	Anodes to refinery
18	Waste heat boilers (8 boilers, 1143 hp each)
19	Waste heat steam to power house
20	Converter balloon flue (18 ft diam)
21	Reverberatory balloon flue (15 ft diam)
22	Multiclone dust collectors (10 sections on converter gases)
23	Multiclone by-pass flue
24	Multiclone outlet flue
25	Stack (reinforced concrete 603 ft 2 in. 39 id bottom, 24 ft id top)
26	Dust handling system
27	Pug mill dust conditioning plant

good life under direct smelting conditions, and all of the original arches were still in place at the end of the first 4½ yr of operation, with No. 2 and No. 3 furnaces each having smelted around 400,000 tons of charge and No. 1 furnace, 600,000 tons of charge at that point. Furnace campaigns average 2 to 2½ yr and major repairs consist of digging out the bottom by blasting and slushing and making repairs to brickwork in the bridgewall, sidewalls, front wall and uptakes and cross-over arches. In the future, greater repairs to the main arches are anticipated because of greater length of service. All silica arches and sidewalls are maintained by the slurry gun patching method developed at United Verde Branch of the Phelps Dodge Corporation. A slurry preparation plant using a 6 × 12 ft ball mill is located at the north end of the reverberatory floor.

Furnace charge is removed from the 265-ton bins above each side of the furnace by 54-in. pan feeders which discharge into drag chain conveyors. The conveyors are 80 ft long with spring gate openings in the box every 4 ft which discharge into hoppers and then into 8-in. charge pipes leading into the furnace.

Table 3 . . . Reverberatory Furnace Data (Dry Tons Basis)

	1942	1943	1944	1945	1946	1947
Concentrate	214,497	355,365	365,923	346,183	316,302	550,979
Precipitate	3,431	6,391	2,231	1,014	738	644
Limerock	9,385	19,149	15,407	18,013	24,832	38,900
Pit Ore	4,705	4,851				
Quartzite	2,088	14,974	7,742	17,823	14,823	38,667
Reverts and Cleanup	5,643	13,079	30,642	10,642	8,232	5,007
Total Solid Charge	239,749	413,809	421,945	393,675	364,927	634,197
Furnace Days	500	706	829	722	596	1,095
Solid Chg. Fce. Day	479	586	509	545	612	579
Mil Btu per ton Chg	5.968	6.539	6.828	6.505	6.270	6.143
Mil Btu per Ton Net	2.670	2.851	3.039	2.958	2.960	2.844
Converter Slag	174,274	269,138	248,076	213,306	211,721	353,431
Reverberatory Slag	174,108	292,309	279,450	248,769	228,565	409,994
Reverberatory Matte	195,755	317,579	319,101	289,524	272,061	450,680
Lb Steam per Ton Concent	3,408	3,980	3,932	3,668	3,387	3,394
Pct Waste-heat Recovery	55.6	56.4	55.5	54.5	52.8	53.7
Pct Boiler Rating	81.4	119.4	101.9	102.8	107.1	101.6

The furnaces originally were equipped with vibrating conveyors, which worked satisfactorily as long as the moisture content of the charge did not exceed the critical point of the vibrators. The moisture content of the concentrate from the filter plant is considerably higher than this point and even after it is lowered by flux additions and by some drying on the beds, the moisture is still close to the critical limit; and when this limit is exceeded trouble is encountered with the vibrators. For this reason the decision was made to replace all vibrating conveyors with drag chains, but because of delay in delivery of material for full length drag chain conveyors it was necessary to make the installation in two stages, the first being short sections of drag chain under the pan feeders which delivered onto the remaining sections of vibrating conveyor. Electrical controls for drag chains and other furnace equipment are housed in two control rooms 15 ft above the floor level.

The furnaces are usually charged four or five times a shift, the charge being distributed evenly over the charge banks from both drag chains simultaneously. It is desirable to have some of the charge run out into the bath in the center channel of the furnace, thus exposing greater area to the combustion flame and to the hot bath in the furnace and providing better contact with liquid converter slag for the reduction of magnetite. If the wet charge in the bath becomes too heavy, it is forced down through the slag and comes in contact with the matte and an explosion occurs. Mild explosions are normal and are desirable because they tend to bring more of the charge in contact with the hot bath, which increases the smelting rate; but at times the explosions may be rather violent and may be hazardous to men working around openings in the furnace or boilers and may cause damage to furnace arches. It is the practice at Morenci to attempt to minimize the force of the explosions by keeping the charge banks well filled so that too much charge does not run out into the bath in one place. It is also the practice to keep tie rods tight and to use steel props on the arch to prevent movement.

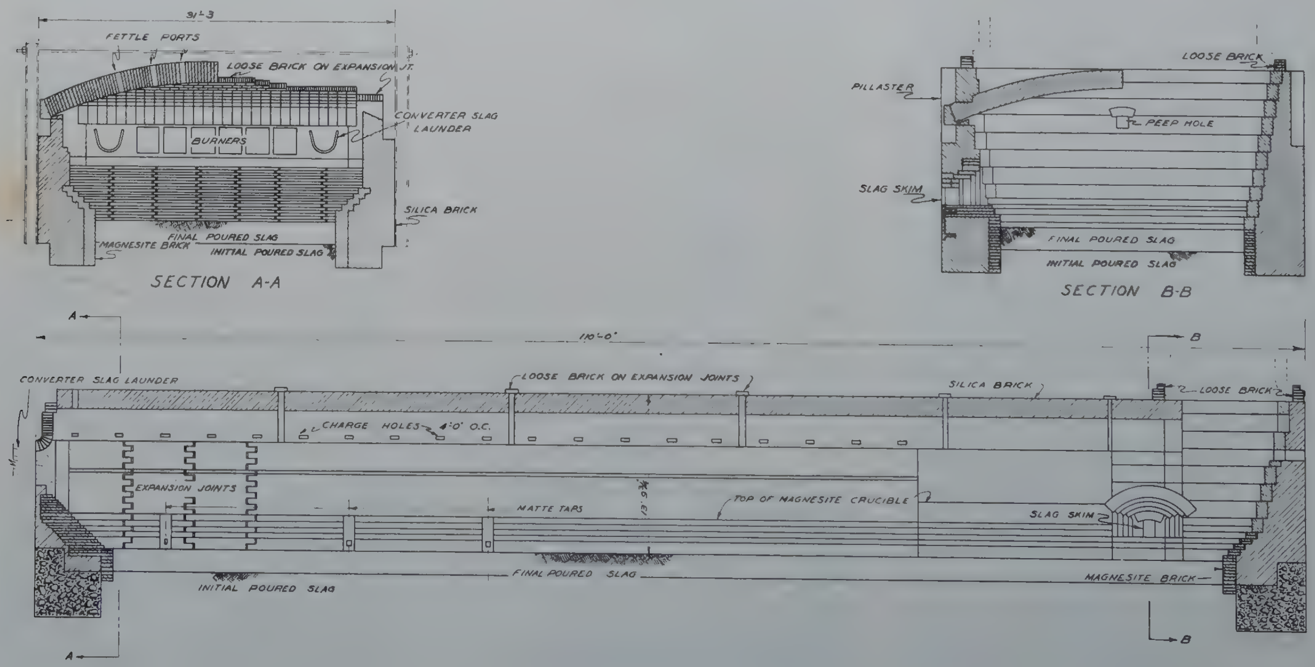

FIG 5—Longitudinal and cross-sectional views of reverberatory furnace brickwork.

The reverberatory furnaces are fired with natural gas and originally were equipped with eight panels of multiple jet burners on each furnace, spaced across the bridgewall with suspended arch construction above the burners. These burners gave satisfactory results, provided the capacity of the burner was not exceeded, but the burners were very difficult to keep clean because of the explosions in the furnace which plugged the burner ports with charge and slag and made control difficult. For this reason and also in order to improve combustion efficiency at higher rates of gas burning a change was made to high pressure burners which enter the bridgewall through large pipes. With large pipes there is less tendency for the burners to become fouled during explosions and combustion control and efficiency are better. The high pressure burners cause somewhat greater arch corrosion as a result of greater turbulence in the combustion zone, but this is not serious and simply requires greater attention to arch maintenance with the slurry gun.

Natural gas from the New Mexico fields is delivered to the plant by pipe line under 300-lb pressure and is then reduced to suitable pressure for use as fuel in the reverberatory furnaces and boilers. Stand-by fuel oil equipment including heaters, pumps and steam atomizing burners has been provided for emergency use and has been used a few times during interruptions to natural gas deliveries.

The natural gas contains about 1100 Btu per cu ft and gas pressure at the burners averages 37 psi, controlled by very sensitive pilot loaded regulators. About 140,000 cfhr of gas is burned in each furnace. Furnace combustion is controlled by frequent analysis of combustion gases with an Orsat apparatus on day shift at a sampling point 75 ft from the bridgewall. Close control of furnace draft is essential to proper combustion and the draft is regulated by automatic dampers back of each waste-heat boiler. Secondary air is largely excluded from the furnace, although some secondary air infiltration is unavoidable and is used to complete the combustion of the natural gas and to burn a small amount of elemental sulphur. No attempt is made to provide excess air for the complete combustion of volatilized first-atom sulphur, as calculations indicate this to be uneconomical. Some sulphur vapor is burned in the furnace, furnace uptakes and boilers, however.

Table 4 . . . Analysis of Reverberatory Solid Charge

	Au	Ag	Cu	SiO_2	Al_2O_3	Fe	CaO	S	H_2O
1942	0.015	0.58	20.98	6.2	1.8	28.1	2.4	37.2	8.33
1943	0.014	0.73	20.49	8.4	1.9	26.8	2.7	35.5	8.25
1944	0.017	0.86	22.49	7.2	1.7	27.8	2.0	34.8	8.09
1945	0.018	1.01	24.35	7.8	1.5	25.1	2.6	34.4	8.55
1946	0.017	0.99	24.55	8.5	1.7	23.7	3.4	33.4	8.43
1947	0.015	1.00	24.10	10.4	1.8	23.1	3.2	32.8	9.04

Some trouble has been encountered with magnetite building up in the reverberatory furnace bottoms. The only source of magnetite is through converter slag additions to the reverberatory furnace, but control of magnetite at the converters is difficult because of the high alumina content of the converter flux. Magnetite in the bath of the reverberatory furnace is partly reduced by contact with sulphides and if free silica is available to combine with the resulting ferrous oxide, magnetite can be fairly well controlled. If free silica is introduced with the charge the smelting rate of the charge is affected adversely and a practice has been worked out of introducing barren quartzite through the arch of the furnace about 20 ft from the bridgewall so that two piles of quartzite, one on either side of the centerline, are maintained floating on the bath in front of the converter slag launders which enter through the bridgewall on each side adjacent to the junction between the sidewall and the bridgewall. By this means free silica is made immediately available when converter slag is introduced and the smelting rate of the charge is not interfered with. This practice has resulted in marked improvement in the control of magnetite and in the protection of furnace bottoms.

Table 5 . . . Analysis of Concentrate Smelted

	Au	Ag	Cu	SiO_2	Al_2O_3	Fe	CaO	S
1942	0.0157	0.618	21.20	2.8	1.4	30.8	0.3	41.2
1943	0.0156	0.806	21.35	4.3	1.3	30.3	0.3	40.9
1944	0.0175	0.932	23.86	4.6	1.4	29.5	0.1	38.8
1945	0.0200	1.180	26.79	3.8	1.3	28.1	0.2	38.8
1946	0.0190	1.126	27.49	4.7	1.5	26.6	0.1	38.3
1947	0.0172	1.132	27.24	5.4	1.6	26.2	0.1	37.6

Table 6 . . . Analysis of Reverberatory Slag

	Au	Ag	Cu	SiO_2	Al_2O_3	FeO	CaO	S	Oxygen Ratio
1942	0.00041	0.0140	0.39	33.6	8.2	50.7	3.3	1.7	1.78
1943	0.00057	0.0165	0.42	34.1	8.5	49.1	3.7	1.5	1.85
1944	0.00034	0.0160	0.46	33.5	7.3	51.3	2.9	1.5	1.73
1945	0.00040	0.0170	0.46	34.2	6.7	51.4	3.3	1.4	1.72
1946	0.00027	0.0155	0.43	35.2	6.6	47.7	4.6	1.3	1.83
1947	0.00029	0.0156	0.44	37.3	6.9	46.0	4.7	1.1	1.99

A deep bath of matte is carried in the furnace at all times unless prevented by high furnace bottoms. Matte-fall is quite uniform throughout the life of each bed and amounts to 70 to 75 pct of the solid charge, or 80 to 85 pct of the concentrate smelted. Matte is tapped through either of three tap holes on each side of the furnace at the bridgewall end, opposite tap holes being used on alternate shifts to allow time for cleaning launders. The matte runs through brick and clay lined launders into 200-cu ft cast steel ladles in the Converter aisle. Two wet pan mills for the preparation of clay for stoppers and launder lining are located at the north end of the reverberatory floor.

Furnace slag is removed from the side of the furnace near the uptake end, the slag skim hole being located just back of the verb arch. The slag is skimmed into 225-cu ft cast steel pots and hauled to the dump by 18-ton electric trolley locomotives. Slag-fall amounts to 65 pct of the solid charge or 75 pct of the concentrate smelted. The slag dump is trimmed and leveled with a bulldozer and the track is thrown with a mechanical track-shifter.

Reverberatory furnace data are shown in Tables 3, 4, 5, 6 and 7.

Table 7 . . . Analysis of Reverberatory Matte

	Au	Ag	Cu	Fe	S	Fe_3O_4
1942	0.019	0.734	27.62	40.6	26.3	11.3
1943	0.019	0.959	28.65	39.8	25.6	8.4
1944	0.022	1.131	31.10	38.3	25.9	7.7
1945	0.024	1.362	34.34	36.0	26.1	9.0
1946	0.022	1.356	34.55	35.2	26.2	6.7
1947	0.021	1.393	35.72	33.9	26.3	4.3

Waste-Heat Boilers

Waste-heat boiler practice with the large water wall area and high steam pressure and temperature has been satisfactory. There are two waste-heat boilers on each reverberatory furnace and each boiler has 11,430 sq ft of total heating surface. Steam is produced at 700 lb ga. pressure and 700°F temperature. The boilers operate at over 100 pct of rating and waste-heat steam produced amounts to 40,000 lb per boiler per hr, which represents a recovery of 53.0 pct of the fuel fired in the reverberatory furnaces.

Combustion gases from the reverberatory furnaces pass through the waste-heat boilers as shown in Fig 2 and 3. The three-drum boilers have internal pendant type superheaters and are equipped with soot blowers using superheated steam on all banks of tubes. The soot blowers are used every 4 hr and are effective in cleaning areas where no sintering or slagging of the dust occurs, but all boilers require complete hand lancing with high pressure air pipes through small ports to remove sintered and caked dust not touched by the soot blowers and to remove slag which forms on the tubes in the area of the boiler inlet from the furnace. Automatic soot blowers on water wall tubes are being considered as a means of lessening hand lancing.

The boiler settings are of fire brick construction with special shapes to fit the water wall tubes. The boiler baffling is shown in Fig 3 and the boilers operate with a draft loss of 0.80 in. of water through the boiler. The crossover connecting flues between the reverberatory furnaces and the waste-heat boiler were made as short as possible to reduce radiation losses. The boiler structures are quite high and this resulted in a stack effect for incoming gases and a back pressure which made an unsatisfactory smoke condition around the boilers. This condition has been overcome by restricting the outlet of the reverberatory furnaces with dampers so that the back pressure in the boilers can be neutralized without upsetting the furnace draft.

Converters

The arrangement of the converter aisle is shown in Fig 2. The aisle is 63 ft wide and 574 ft 6 in. long, with crane rails 57 ft 6 in. above the ground and a span of 60 ft between crane rails. The three cranes each have two 60-ton hoists driven by 100 hp direct-current motors with magnetic brakes on the motor shaft and gear train. Two 5-ton repair hoists and one 50-ton repair hoist are located above the crane runway.

Table 8 . . . Converter Data (Dry Ton Basis)

	1942	1943	1944	1945	1946	1947
Matte	195,755	317,579	319,101	289,524	272,061	450,680
Pit Ore	46,854	70,420	45,801	41,956	35,530	71,244
Other Material	175	1,703	4,569	1,796	9	
Quartzite	19,193	25,615	43,639	29,594	28,625	42,292
Reverts	30,994	40,916	32,608	46,927	50,420	84,567
Copper	47,027	79,740	88,315	92,110	85,794	148,402
M Cu Ft air per Ton Cu	244.0	233.7	210.1	172.9	165.1	171.4
Percent Blowing Time	66.4	64.8	64.0	51.8	59.6	58.2
Average Converters Operating	2.70	2.97	3.26	2.84	3.31	4.00

There are six 13- × 30-ft Pierce-Smith converters located on 60-ft centers. The converter shells are 1½ in. steel plate, welded construction with heavy reinforcing plates along the tuyere section and around the mouth. The welded steel riding rings are riveted to the shell at the outer ends of the shell. The converter ends are made of 1 in. welded plate with 4 beam stiffeners on each end and the ends are held in place by bolts and springs to allow for expansion. The springs have been of value in relieving expansion after repairs, but a point is reached where the springs cannot be used without digging out the entire end sections of the converter and re-setting the end plates in their original position.

The converters are driven by 75 hp dc motors with magnetic brakes, through a speed reducer, intermediate gears and pinion and large gear which is bolted to one of the riding rings. Direct-current for operation of converters, cranes, anode furnaces, and slag locomotives is generated by two 600 kw fly-wheel motor-generator sets and one 300 kw stand-by motor-generator set located in control rooms behind the converters. If the direct current generators and the turbo-blowers in the power house are put out of service by a power failure, the fly wheels can furnish sufficient power to turn down the converters and to allow the cranes to be moved. A signal on the converter air main sounds an alarm when the air pressure drops below a pre-determined point.

The converters have 52 ball valve tuyeres with threaded connections arranged so that 10 tuyeres on each end have 2-in. tuyere pipes and the 32 tuyeres in the center have 1½-in. tuyere pipes. There are two Garr guns, one on each end, for flux which is drawn from overhead bins of 250 tons capacity for each converter into 5-ton measuring hoppers at each Garr gun. The Garr guns are used alternately to even the wear on the brick lining.

In normal operation, the converters are charged with 5 ladles of matte, amounting to about 70 tons, and additional matte is added after fluxing, blowing and skimming. Air pressure of 13 lb at the converter tuyeres has been found best for converter operation. Air volume averages 23,000 cfm at the tuyere with periods of 25,000 cfm. Air consumption is measured by indicating and recording meters on the 24-in. air line leading to the blast gate and wind box on each converter. An electrical signal system between the converter aisle, the power house, and the smelter office indicates and records the blowing time of each converter and shows which converters and which blowers are in operation at any time.

In making copper charges, matte is blown to white metal in two converters and the white metal from one converter is then transferred to the other and the copper charge finished in that converter. Copper charges average 90 tons and the copper is blown to "worm" copper for the anode plant. Oxide slag is formed in the converter at this stage of the blow and this slag is very corrosive on the brick lining and must be handled with care to prevent explosions when it is skimmed and transferred to another converter. After each transfer or charge of copper is completed the tuyeres are reamed with a cutter bar clamped in a light rotating drill which is supported by hand. This method of reaming tuyeres is much easier on the brick work than the use of a sledge hammer and cutter bar.

Converter campaigns between tuyere line repairs average 9000 tons of copper. No magnetiting of converter linings has yet been practiced. Hard burned chrome-magnesite brick is used in converter linings and repairs are made with the 18-in. four-piece tuyere block shown in Fig 6. The normal repair includes a number of courses in 18-in. wedge brick above and below the tuyere blocks and it is usually necessary

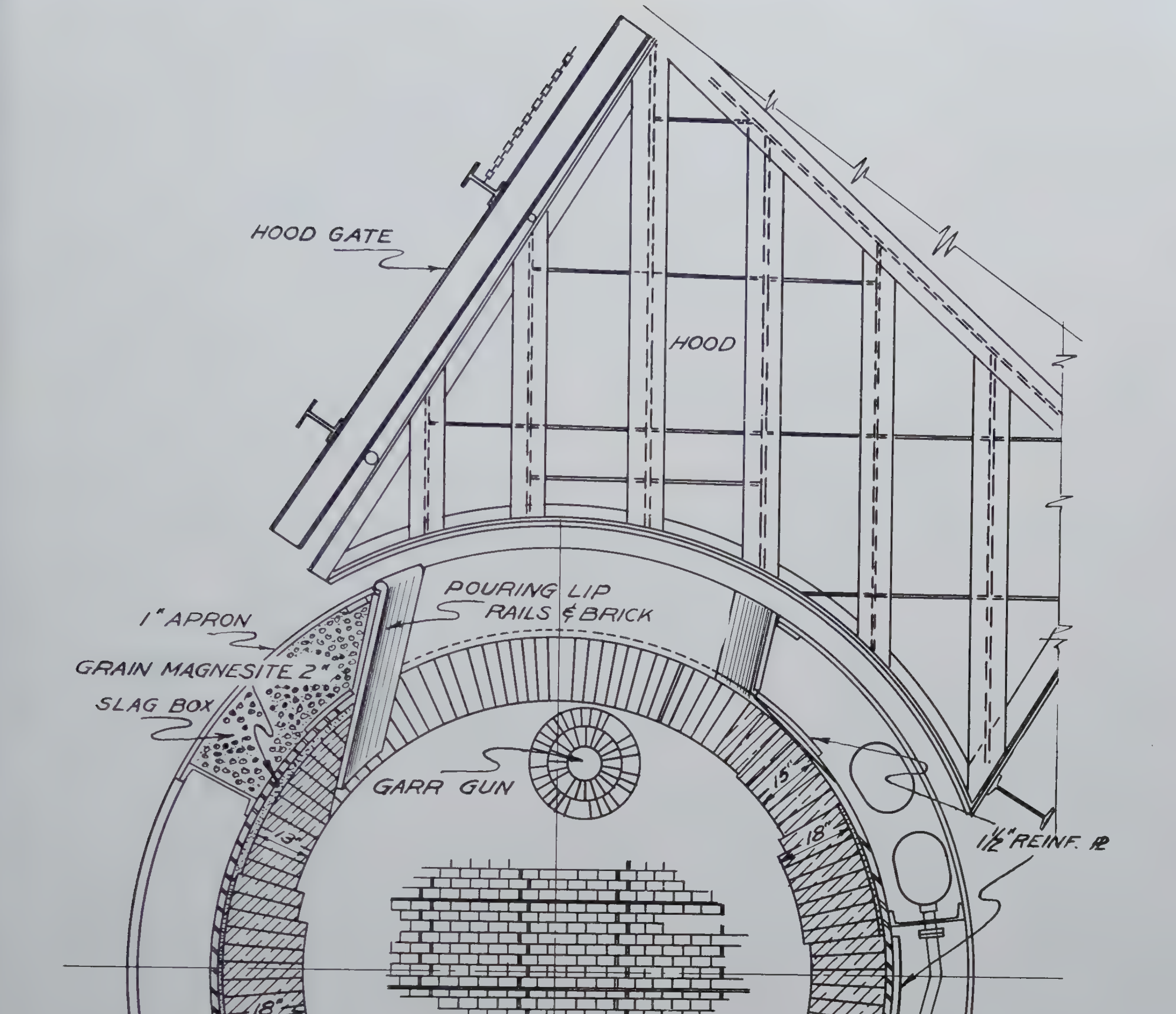

FIG 6—Converter brickwork.

Table 9 . . . Analysis of Converter Slag

	Au	Ag	Cu	SiO_2	Al_2O_3	Fe	CaO	S	Fe_3O_4
1942	0.0038	0.0886	2.85	24.9	5.0	48.0	0.4	2.1	14.6
1943	0.0020	0.0829	2.91	23.5	5.4	47.9	0.4	1.7	13.7
1944	0.0016	0.0699	2.48	23.8	4.5	49.7	0.4	1.6	16.0
1945	0.0018	0.0780	2.52	23.1	4.5	50.5	0.3	1.7	20.4
1946	0.0014	0.0905	2.87	24.6	4.4	47.4	0.3	1.6	20.3
1947	0.0013	0.0834	2.93	26.2	4.9	45.5	0.7	1.5	18.0

Table 10 . . . Analysis of Pit Ore for Converter Flux

	Au	Ag	Cu	SiO_2	Al_2O_3	Fe	CaO	S
1942	0.0014	0.029	0.83	65.3	15.7	3.7	0.6	3.6
1943	0.0012	0.041	0.96	65.3	17.5	3.4	0.5	2.9
1944	0.0012	0.050	1.01	65.5	18.2	3.2	0.4	2.6
1945	0.0052	0.049	1.05	65.8	17.9	3.3	0.4	2.6
1946	0.0012	0.050	1.09	65.1	18.1	3.4	0.2	2.7
1947	0.0011	0.052	1.19	65.6	17.9	3.3	0.6	2.8

to extend the repair to include the arches at the back of the collar, and occasionally necessary to dig out and brick a section in the bottom or front of a converter. Spalling after repairs is avoided entirely by allowing proper expansion joints and by heating the converter very slowly with gas burners for about 48 hr until the entire brickwork is practically at operating temperature and then washing the converter with slag to seal the joints, and charging with matte while the converter is still near maximum temperature. The pouring lips on the converters are made with magnesite brick held in place by rails and grouted with magnesite ganister. The space between the 1-in. apron plate and the shell below the pouring lip is boxed in and filled with magnesite ganister to prevent metal leaks around the brick pouring lip.

Converter hoods are of welded steel construction with cast iron liners in the lower portion. The hood gate rolls on rails and is raised and lowered by motor driven sprockets and chains. A butterfly damper in the circular section of the converter uptake flue is operated by high pressure air with control valves on the skimmer's platform.

Table 11 . . . Analysis of Barren Quartzite for Converter Flux

	Cu	SiO_2	Al_2O_3	Fe	CaO	S
1942		85.4	5.3	2.8	0.9	0.3
1943		79.4	9.5	2.8	0.8	0.3
1944		80.9	8.5	2.6	0.3	0.2
1945		84.0	6.0	3.0	0.5	0.2
1946		84.8	6.3	2.5	0.6	0.2
1947		85.6	5.3	2.1	0.9	0.2

Converter puncher's platforms are raised and lowered for adjustment by hydraulic lifts using oil pressure, and each platform has an air cooling system of overhead ducts with slots for blowing low pressure air from individual motor driven blowers. Stationary platforms behind the converters connect all punchers platforms and also connect with the skimmers platforms.

Converter cleanings, hood cleanings and dust from the hoppers back of the converters are collected in boats on wide gauge cars which are pulled backward behind the converters onto a transfer car running parallel to the converters and reaching the converter aisle under the cranes at the south end of the aisle. The transfer car track is directly underneath the dust hoppers behind each converter and dust is easily drawn into the cars as they are pulled from under the converters. The cleanup in front of the converters is done with a weighted drag handled by the converter crane, and a Traxcavator is used for loading the cold material into boats. Matte and slag ladles are shelled into a skull breaker with an elevated bumping block in the south end of the converter aisle; and cold material from the skull breaker is hauled to the smelter crushing plant in railroad cars.

Converter data are shown in Tables 8, 9, 10, 11 and 12.

Table 12 . . . Analysis of Mixed Converter Flux

	Au	Ag	Cu	SiO_2	Al_2O_3	Fe	CaO	S
1942	0.0015	0.033	0.69	71.3	12.1	3.5	0.8	2.3
1943	0.0013	0.048	0.76	70.3	14.9	3.2	0.5	1.8
1944	0.0015	0.074	0.89	72.6	13.0	3.2	0.4	1.5
1945	0.0023	0.211	2.68	66.4	10.6	8.3	0.5	2.4
1946	0.0017	0.082	1.98	64.5	9.4	11.6	0.8	2.0
1947	0.0013	0.063	1.43	65.0	10.6	10.2	1.5	2.0

Anode Plant

All Morenci copper is produced as anode copper for economy at the refinery. The anode plant is located at the north end of the converter aisle as shown in Fig 2 and contains two refining furnaces of the same type as the converters, but with shells 13 × 25 ft instead of 13 × 30 ft, and one casting wheel. Anode plant practice with rotating furnaces is entirely satisfactory and the arrangement of two refining furnaces and one casting wheel provides flexibility and storage capacity for uniform converter operations.

The anode furnace shells are made of 1½-in. plate, welded construction, with riding rings at the ends and with openings for the poling and skimming door and casting spout. The ends of the vessels are made of 1-in. welded plate with reinforcing beams which are fastened rigidly to the shell. The ends have openings for the receiving spout, burner port and stack outlet. The direct current motors and gear drives are duplicates of those used on the converters.

The anode furnaces are heated with natural gas in burners using high-pressure air for short flame combustion. The burner enters through one end wall well above the metal line. Anode charges average 175 tons of copper and two converter charges usually fill an anode furnace. The anode charges are blown with high-pressure air using two ¾-in. pipes to eliminate the sulphur, the slag is skimmed off and the copper is poled with oak or pine poles which are manipulated with an air operated hoist. The anode furnaces are surrounded by a large concrete platform at an elevation 2 ft below the centerline of the furnaces which provides working space for the blowing, skimming and poling operations.

Copper is poured from the anode furnaces into hydraulically operated pouring spoons and then into copper molds on a circular casting wheel 40 ft in diam with 26 molds. The wheel is electrically driven through gears by duplicate motors which turn the wheel in either direction. All operating controls for the anode vessels, pouring spoons, and casting wheel are located in cabs at each side of the casting wheel. The wheel is moved by an automatic timing device which controls the rate of casting; and the wheel stops automatically with one mold in proper position under the pouring spoon and another mold in proper position for lifting the anode

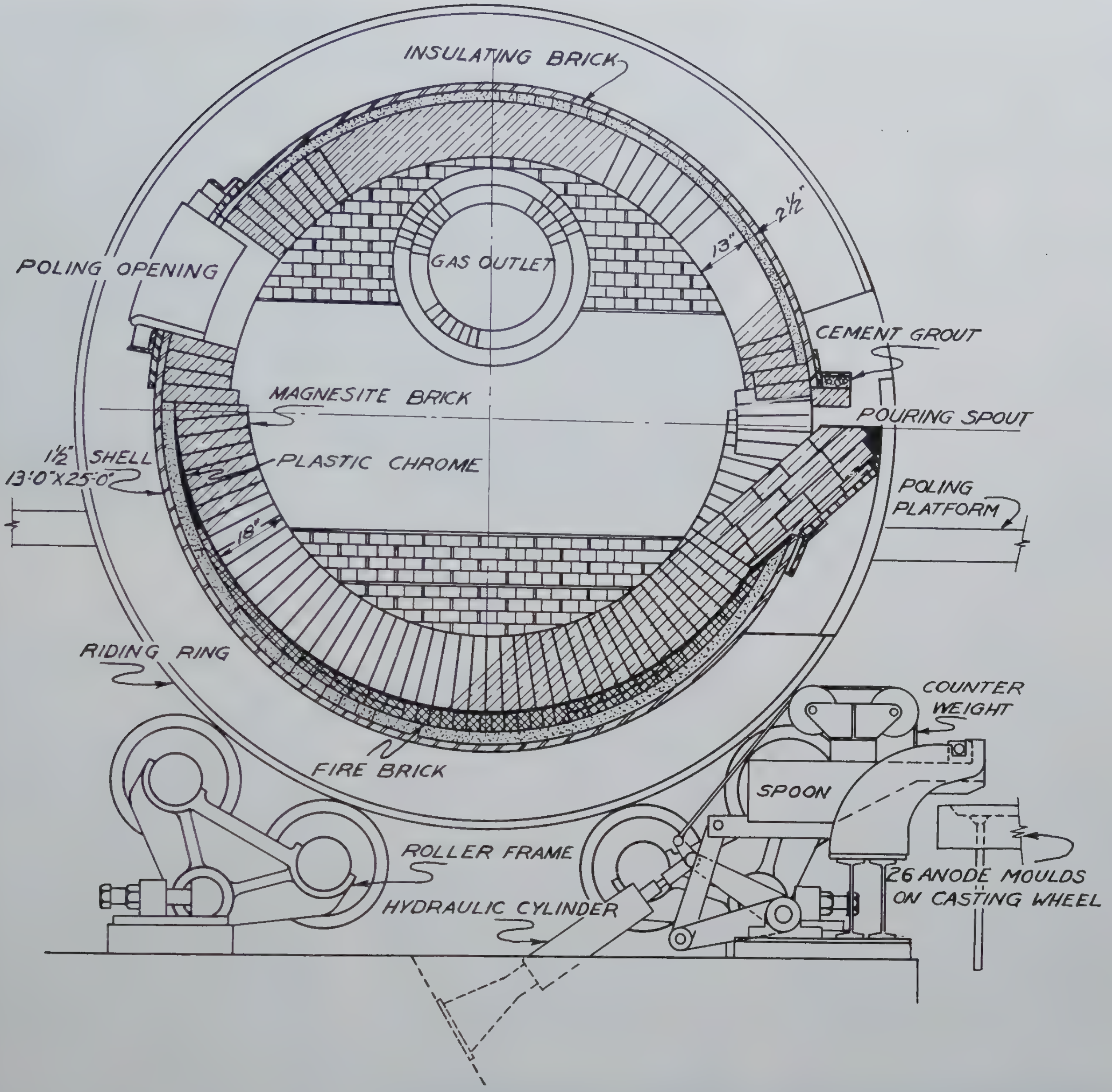

FIG 7—Anode furnace brickwork.

from the mold by tongs. Pouring speed averages 30 tons per hr.

The liquid copper poured into the mold from the spoon must chill on the surface before the casting wheel is moved to prevent rolled edges and fins on the anodes; and a blast of converter air automatically controlled by a solenoid valve, is used to speed up the cooling of the surface of the anode. Water cooling of the molds and anodes is accomplished by spray pipes at definite locations on the wheel. The empty molds on the casting wheel are sprayed inside while hot with an alumina sand wash to keep the anodes from adhering to the mold.

The anodes, which weigh 700 lb, are raised from the molds by pins with sliding contact on an inclined track, and are lifted from the pins and placed in bosh tanks by manually operated air tongs with control valves at the side of the bosh tanks. Anodes are removed from the bosh tank by a 15-ton crane, inspected and trimmed on the floor adjacent to the anode plant and are then loaded into railroad cars by 2-ton storage battery trucks with vertical lift arms. A large concrete floor across the track from the anode floor is used as a copper dock for storage of anodes during periods of interrupted shipments. This floor and the trimming floor is armored with cast iron grids cast in the concrete.

Pouring spoons are lined with a cement-sand mixture. The spoons and cast iron master molds are heated to the proper temperature for use by individual gas burners. Copper molds for the casting wheel and copper tapping plates for the reverberatory furnaces are made on day shift. The copper molds last for about 300 tons of anodes each before cracking too badly to use. One or two new molds are put on the wheel daily and the discarded molds are returned to the converters for smelting with the copper charges.

Anode furnace lining is shown in Fig 7. The chemically bonded magnesite brick has given excellent service and no major repairs to the brick lining have been made in the first six years of operation. Brickwork over the poling doors and around the openings in the ends of the furnaces is maintained by slurry gun patching with magnesite cement when required. The complete insulation of the shells is desirable for fuel economy and for better working conditions and to prevent filling up of the bottoms with refractory slag.

Anode Plant data are shown in Table 13.

Table 13 . . . Analysis of Anode Copper

	Au	Ag	Cu	S	O_2	Anode Plant Data Per Ton Anode Copper	
						Lb Poles	Fuel Mil Btu
1942	0.071	2.75	99.72	0.0036	0.140	80.30	1.26
1943	0.071	3.50	99.72	0.0017	0.123	81.64	1.35
1944	0.077	3.93	99.70	0.0021	0.128	81.73	1.36
1945	0.076	4.13	99.69	0.0019	0.124	98.78	1.50
1946	0.070	4.03	99.74	0.0017	0.100	67.34	1.24
1947	0.064	4.13	99.76	0.0018	0.098	62.08	0.89

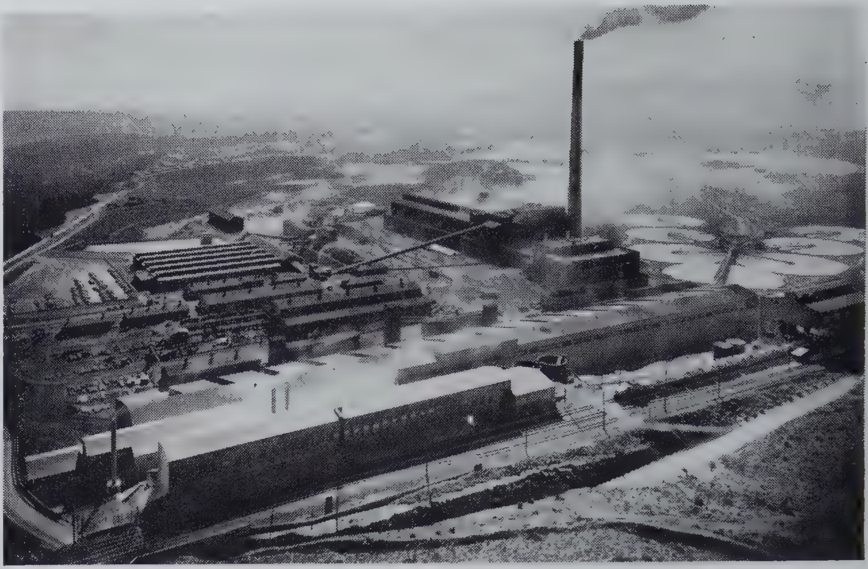

FIG 8—General view of reduction works.

Flues and Stack

The entire flue system in the Morenci Smelter is of steel construction well insulated to prevent heat loss, and of large cross-sectional area to reduce gas velocities. Arrangement of the flue system and stack is shown in Fig 2. The steel balloon flue located back of the converters turns at right angle and rises in a vertical box connection to cross the converter aisle above the crane runway. Gases pass from this flue through mechanical dust collectors consisting of 10 sections of 16-in. Multiclone tubes, and then to the stack. The converter flue is 18 ft in diam and is covered with 2 in. of fiber glass insulation from a point near the first converter to the dust collectors. The flue immediately back of the converters is not insulated. The mechanical dust collecting system is insulated and also the 18-ft balloon flue leading from the dust collectors to the stack.

A 15-ft steel balloon flue for reverberatory furnace gases, also insulated, leads from the waste-heat boiler outlets and joins the converter flue just in front of the portal of the stack. There is an automatic damper in the reverberatory flue which is operated by a motor driven worm gear actuated by an electric eye connected to a draft gauge. The necessity for a dust collecting system on the reverberatory gases has not yet been determined.

FIG 9—View of reclaiming machine.

The stack was built of reinforced concrete with a lining of acid proof brick laid in acid proof mortar and with insulation between the concrete shell and the lining. The stack is 603 ft 2 in. high, with a foundation 9-ft thick and 71 ft in diam standing on a consolidated conglomerate earth foundation with a loading strength of 5 tons per sq ft. The stack was designed to withstand a wind pressure of 100 mph. It is protected by lightning rods with copper cables to the ground. The inside diameter of the stack is 39 ft at the bottom and 24 ft at the top. The concrete shell is 36 in. thick at the bottom and tapers to 7 in. at the top. The total weight of the stack and foundation is about 10,000 tons.

The stack was designed for a draft of 3 in. of water with gases at 500°F and an outside temperature of 60°F and has a total capacity of 1,000,000 cfm at stack conditions. The high stack draft is necessitated by the use of mechanical dust collectors on the converter gases which operate with a pressure drop of 2 in. water. The remaining draft is lost in friction and at the converter hood openings.

The stack was built with two portals, one main portal and a smaller one directly opposite. The smaller portal has been bricked up and will be used only in case it is desired to divert part of the gases through a dust collecting system on the opposite side of the

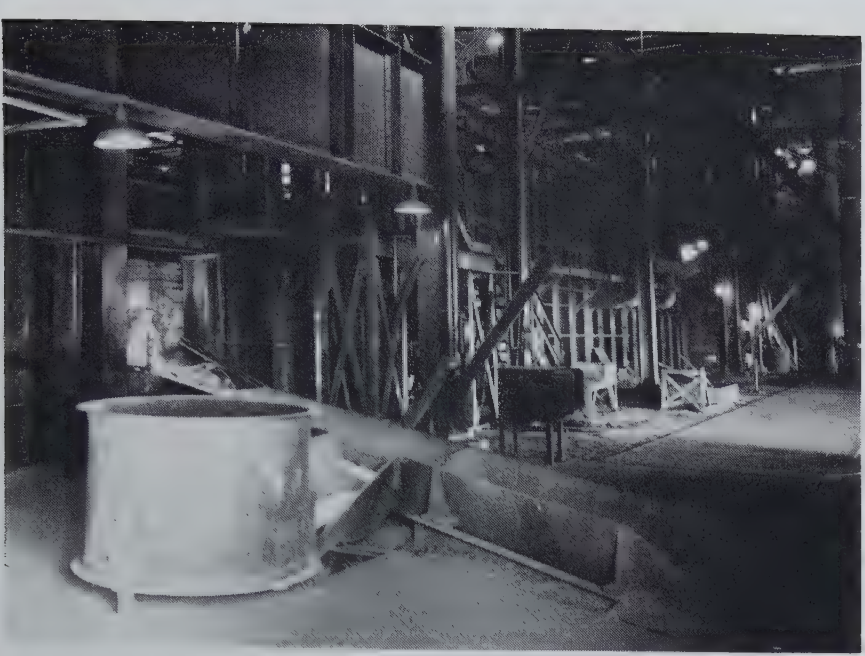

FIG 10—View of reverberatory furnace skimming end.

stack. A test station is located 274 ft above the ground for testing stack gases.

Flue dust handling is accomplished mechanically by means of drag chain conveyors in the bottom of the balloon flues and screw conveyors under the multiclones. The granular abrasive dust from the balloon flue immediately back of the converters however is returned to the converter dust hoppers by gravity through 10-in. pipes at each hopper. The combined dust from the balloon flues and multiclones is collected in a surge bin and is then removed by a short screw feeder, mixed with air and pumped pneumatically to a pug mill located near the junction house through which pass the conveyor belts carrying concentrate from the filter plant to the bedding plant. The flue dust in the pug mill is sprayed with water until properly conditioned and is then discharged onto the layer of concentrate on the belt conveyor and delivered along with the concentrate to the bedding plant.

Power Plant

The Power Plant, which is under separate supervision, is situated about 500 ft from the waste-heat boilers. Steam from the waste-heat boilers at 700 lb pressure and 700°F temperature is delivered to two direct-fired superheaters in the power house, emerging from the superheaters at the proper condition for utilization at the turbine throttle, namely 650 lb ga. pressure and 825°F temperature. Three direct-fired water-wall boilers of 1430 hp each, using natural gas fuel with automatic burner control and air pre-heaters, and with stand-by fuel oil for emergency use, furnish additional steam which is combined with the waste-heat steam in the direct-fired superheaters. About 60 pct of the total steam is produced in the waste-heat boilers and 40 pct in the direct-fired boilers.

Steam is utilized in four 15,000 kva maximum capacity turbo-generators with surface condensers. Power is generated at 13,200 volts and is transmitted to the Concentrator, Smelter, Open Pit mine and pumping stations at this voltage and is there stepped down to 2,300 volts and 440 volts for plant use. A very good power factor results from the use of a large number of synchronous motors in the Concentrator.

Condenser cooling water is pumped through concrete pipes to a cooling tower 1300 ft away. Evaporators are used for boiler feed water make-up and boiler feed water is deaerated, heated to 300°F and pumped to the waste-heat and direct-fired boilers by 8 stage electrically driven centrifugal pumps with steam pumps as stand-by. Waste-heat boiler feed water is delivered through 5-in. welded steel insulated lines with automatic control at the pumps and at the boilers. Steam is returned to the power house from the waste-heat boilers through two 10-in. welded steel insulated lines.

During periods of curtailed power requirement at the Open Pit Mine and Concentrator on scheduled week-end shut-downs, excess waste-heat steam is diverted to a separate condenser plant outside the power house. Cooling water for this condenser plant is circulated through the same system used for the condensers on the turbo-generators and condensate from the condenser plant is returned to the boiler feed water system.

Compressed air at 100 lb pressure is produced in two 3,730 cfm electrically driven compressors located on the ground floor of the power house. Con-

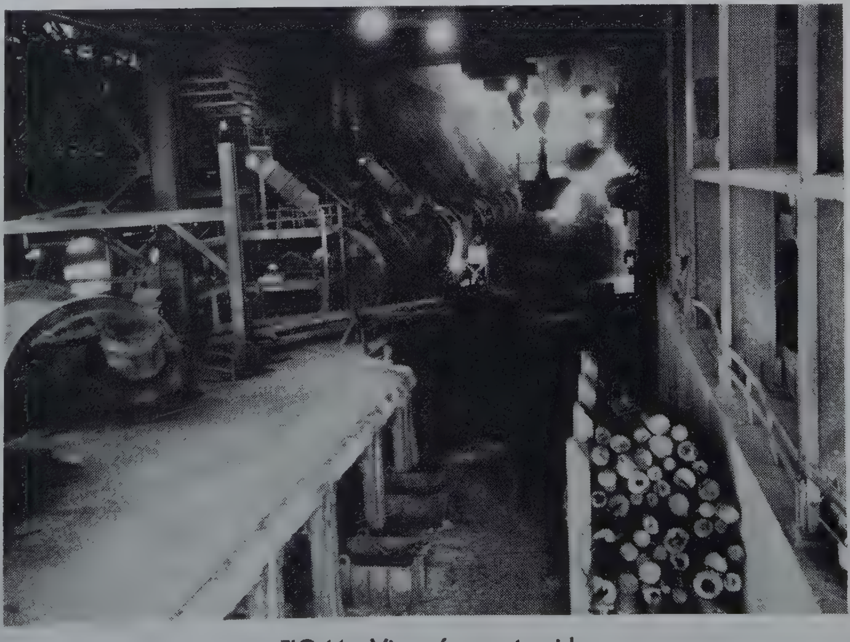

FIG 11—View of converter aisle.

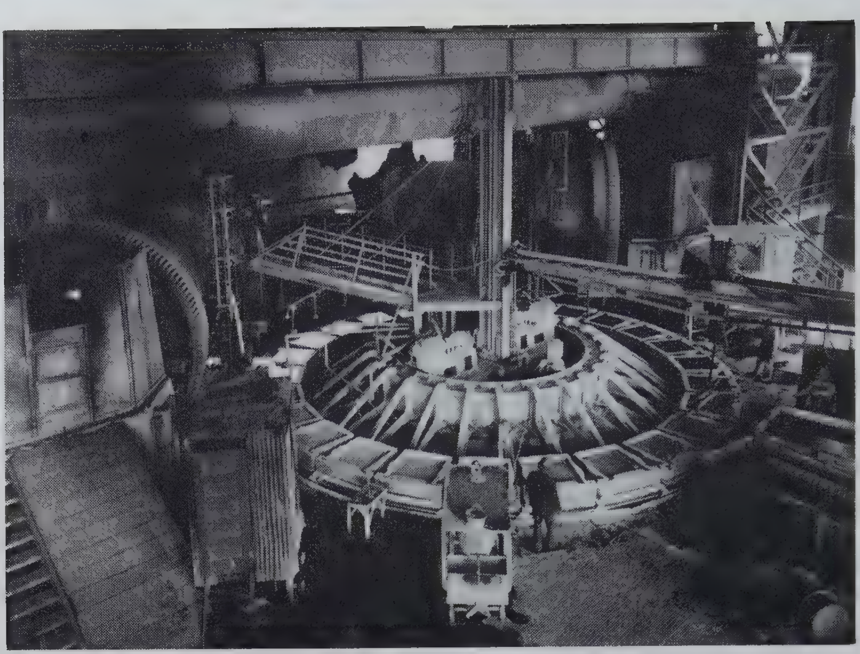

FIG 12—View of anode plant.

verter air is produced by six electrically driven turbo-blowers of 27,500 cfm capacity each at 12.5 lb barometer and 100°F. The blowers are direct-connected to 1500 hp induction motors and operate at constant speed and pressure with automatic regulators controlling impedance vanes on the inlet air ports to adjust air volume to requirements. Converter air is produced at 14 lb pressure and 275°F at the blowers and the blowers discharge into a header pipe connected to a 60-in. air main leading to the converters. Air volume is metered for each blower between the blower and the header pipe. (Fig 8-12)

Smelter Organization

Smelter operations are under the supervision of the smelter metallurgist, with a general foreman over the reverberatory department and another over the converter department. Shift operations in the reverberatory, converter and anode departments are under the supervision of shift foremen, and the crushing, bedding and reclaiming plant, lime burning plant, brickmason crew, repair crew and labor crew are each under the supervision of a day shift foreman.

The Smelter maintains a technical staff for plant testing and investigation and a safety department which is a part of the Branch safety organization.

Smelter maintenance work is carried out by the smelter repair crew and brickmason crew, while heavier work is done by the well equipped shops at the Reduction Works.

The Interaction of Liquid Steel with Ladle Refractories

CARL B. POST* AND GEORGE V. LUERSSEN,* Members AIME

It is generally recognized that nonmetallic inclusions in steel come from two principal sources. First are the chemical reactions in the furnace, or in subsequent deoxidation, resulting in slag which does not free itself from the metal. Much information has been published concerning these chemical reactions and their control through proper attention to slag viscosity, composition of deoxidizers, and other qualities. The studies of this subject by C. H. Herty, Jr. and others through the medium of physical chemistry have yielded much information for the steelmaker. The second source is erosion of ladle refractories, such as lining brick, stoppers, nozzles and runners, causing entrapped particles of globules of fluxed silicate material. In contrast with the large amount of information available on the first source, relatively little has been published on the subject of erosion which, in the case of basic electric melted steel, is the principal source of nonmetallics. This is probably due to the fact that the problem was assumed to be one of simple mechanical erosion, which could be solved primarily by modification of ladle practices. Good improvements have been made by elimination of slurries in the ladle, better ladle and runner refractories, and more attention to pouring temperatures. It is doubtful, however, that this problem has been recognized in its true light since it is not one of simple mechanical erosion but rather one of chemical reaction between the metal and the refractories; and in this sense is as much a problem of physical chemistry as the reactions involved in the actual steelmaking process.

The influence of ladle refractories on the resulting cleanness of steels was early recognized by A. McCance[1] who examined large inclusions in steels made by both acid and basic practices. His chemical analyses showed the large influence exerted by the manganese content of the steel on erosion of the ladle and nozzles used in those days. The presence of MnO in such inclusions led McCance to the hypothesis that both basic and acid steels react chemically with the ladle refractories so that small globules of fluxed refractories are carried in the stream into the molds.

This early work of McCance was checked by one of the present authors on basic electric bearing-steel, and it was found that on steels containing as low as 0.40 pct manganese the fluxed surface of the ladle lining after delivering such a heat showed as high as 25 pct MnO by actual analysis. Furthermore, by lowering the manganese content of the steel to 0.20 pct, ladle erosion was decreased with a corresponding decrease in silicate inclusions in the steel. Limitations placed on the manganese content for the required inherent properties made it impossible to pursue this line further, and subsequent attention was concentrated on improved ladle refractories, care in keeping the ladle clean and free from loose refractories up to the time of tapping, and pouring the steel at optimum temperature.

Our study of the chemical reactions at the metal-brick interface between steel and ladle refractories was revived in 1939 as a result of an experimental observation made on the cleanness of alloy steels of the SAE types. This observation showed that the relative cleanness of such steels made in basic electric arc furnaces of 12 ton capacity and poured in ingots ranging from 1100 to 2200 lb weight was determined to a large extent by the ratio of the manganese and silicon contents, provided other steelmaking variables such as tapping temperature, pouring temperature, pouring time, amount of aluminum added for grain size control, and degree of deoxidation in the furnace were kept reasonably constant. Detailed studies made on the deoxidation and slag practice during the refining period of basic electric furnace practice showed that these two variables exerted some influence on the resulting cleanness of steel in the form of bars and forgings. The important variable, the manganese-silicon balance, was not apparent until heats were made in succession by the best furnace practice kept under fairly rigid metallurgical control.

Another observation pertinent to this work concerned the similarity in the microscope of slag particles causing magnaflux or step-down indications in subsequent rolled bars, and the patches of slag frequently seen on the surface of ingots. These patches are generally believed to come from the glassy metal-brick interface in the ladle and represent an entrapment of such glass (both from the ladle brick and nozzle) in the metal as it flows over the refractories in the neighborhood of the nozzle. These glassy particles are carried down into the mold with the liquid steel, and gradually coalesce into a slag "button" which floats on the surface of the steel as it rises in the molds. Periodically the button is washed to the side of the ingot where it is trapped between the surface of the ingot and the mold, later appearing as a slag patch on the surface of the ingot after stripping.

Even though most of the small glassy particles coalesce into a slag button while the ingot is being poured, it is logical to suspect this step in the steelmaking process as being a source of slag lines large enough to cause trouble

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[1] References are at the end of the paper.

on subsequent magnaflux inspection in rolled bars. This is especially true when the furnace practice is known to produce clean steel as shown by samples taken from the furnace just before tapping, and also spooned from the ladle before starting to pour. During the pouring of an ingot, the stream from the nozzle is playing in the center of the mold, and the turbulence created by the stream is such that any particles trapped in the stream will be carried for quite a distance down into the molten metal in the mold, and will then be carried over to sides of the molds before finally reaching the upper surface of the metal. It is to be remembered that the metal is freezing rapidly at the wall of the mold, and that a zone of mushy metal extends inward from the wall. Thus the small slag particles stand a good chance of being trapped in this mushy metal and their chance of doing so should increase as the temperature of the metal is colder or as the rate of pouring the ingot becomes slower.

Now, knowing that a relationship exists between the chemical composition of the steel and the resulting magnaflux inspection of bars and forgings, and further, that a large percentage of the slag particles large enough to cause these magnaflux indications appear to have the same silicate characteristics as the so called "ladle-wash" or metal-brick interface, it seemed reasonable that a detailed study of acid slags formed by the interaction of the ladle brick and the liquid steel would lead to an explanation and correlation of these effects. Before proceeding to examine the actual data resulting from this study, we would like to state the problem of this interaction of ladle refractories and liquid steel in qualitative detail.

In the first place, molten steel will be tapped from a basic electric arc furnace into a ladle lined with brick analyzing 65 pct silica, 30 pct alumina, and 5 pct Fe$_2$O$_3$.* At the metal-brick interface there will form as a result of temperature effects a layer of fused glassy slag which will initially be the composition of the brick. The molten steel, however, contains certain elements and constituents such as manganese, silicon, and ferrous oxide, which will lead to a change in the chemical composition of the fused glass. The composition of the fused glass interface will be modified therefore so that MnO and FeO make their appearance according to the balanced relationships known to exist between slags containing SiO$_2$-MnO-FeO-Al$_2$O$_3$ and liquid steel containing Fe-Mn-Si-FeO. Thus, depending upon the manganese and silicon contents of the metal and its temperature, the so-called equilibrium slag will be high or low in manganous oxide and high or low in silica, and consequently of high or low fluidity. The appearance of MnO and FeO in the glassy interface as a result of this reaction will cause a decrease in the weight percentage of SiO$_2$ and Al$_2$O$_3$ due to dilution. Depending upon the final composition of this glassy interface, it will slough off easily or with difficulty, as measured by its fluidity or viscosity at the temperature of the interface. Thus the number and composition of the inverse rain of particles trapped in the flow of the metal near the nozzle and carried through the nozzle with the steel, will depend to a large extent upon the chemical composition of the interface and its fluidity or viscosity. The saturation solubility of SiO$_2$ in slags of this sort is approximately 50 pct by weight and does not vary greatly with temperature. Furthermore, viscosity studies of acid slags containing MnO, FeO, and SiO$_2$ show that as the acid slag approaches saturation of SiO$_2$ the viscosity increases greatly.

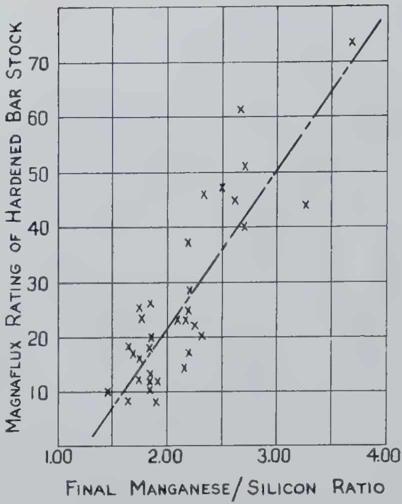

FIG 1—Cleanness of SAE 6150 aircraft quality as a function of the final Mn/Si ratio.

In view of the above remarks, it appeared worthwhile to review Körber and Oelsen's[2] work on equilibrium in the system Fe-Mn-FeO-SiO$_2$-Al$_2$O$_3$ and to set up a system of calculation so that their results could be extrapolated to cover the equilibrium between molten steel and the glassy interface at the ladle brick. Such a system allows the composition of the equilibrium acid slag to be calculated if the analysis of the metal is known, and this calculated acid slag can be compared with the experimental values obtained for slag "buttons" or slag patches on the side of ingots. If some agreement is obtained by these methods and the experimental data, then it is reasonable to conclude that the occurrence of these slag patches, and also the greater part of the slag-lines in the finished bars, are influenced largely by the interaction of the molten steel with the ladle brick. Conversely, and this is most important, if the composition of the steel can be shown to influence the final cleanness of the steel, then the problem can be studied with a view to finding general rules for adjusting the composition of the steel to obtain as clean steel as possible.

This report is accordingly divided into three parts. Part 1 will show the step-down data and operating conditions in the furnace, ladle and pit for two grades of SAE steels, SAE 6150* and SAE 3312†. This part will show that if the furnace practice, ladle and pit practices are kept reasonably constant, then there is a relationship between the manganese and silicon ratio in these two grades of steel and the resulting cleanness. This conclusion will be based both upon the results of our own inspection department and upon magnaflux inspection data of a leading aircraft engine manufacturer. In addition, performance records of a new deep-hardening roller-bearing steel in which the silicon content is adjusted to balance the high manganese content is compared with a similar grade containing high manganese and low silicon contents.

Part 2 will show the chemical analysis of many heats of steel and of the corresponding slag-buttons and slag-patches taken from the sides of ingots. These data will be correlated to show that the manganese-silicon balance of

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* Throughout this paper repeated reference will be made to the metal-brick interface in the ladle as the principal example of metal-refractory interaction. However, in the case of ladles using bonded graphite nozzles, the clay bonding material will react in the same manner we ascribe to the ladle brick. Similar remarks will apply to clay or sand mixtures used in the well of the ladle to seal the nozzle in place, and to the bonded graphite heads and sleeves used on the stopper-rod.

* SAE 6150: 0.48/0.55 C, 0.65/0.90 Mn, 0.20/0.35 Si, 0.040 max. P, 0.040 max. S, 0.80/1.10 Cr, 0.15 V Min.

† SAE 3312: 0.08/0.13 C, 0.45/0.60 Mn, 0.20/0.35 Si, 0.025 Max. P, 0.025 Max. S, 1.40/1.75 Cr, 3.25/3.75 Ni.

Table 1 · · · Typical Melting Log of SAE 6150

Time	Log	Addition Pounds		Metal Tests									Slag Tests							
				C	Mn	Si	P	S	Cr	Ni	V	FeO	SiO_2	CaO	CaF_2	C (Free)	CaC_2	FeO	MgO	CaS
11:20 AM	Power on																			
11:20 to 11:55	190 V																			
11:55 to 12:15	160 V																			
12:15 to 12:30	130 V																			
12:30	Charged reducing slag—																			
	Lime	300																		
	Spar	80																		
	Coke	40																		
12:55	No. 1 Carbon test			0.42	0.45				0.55											
12:57	Spec. test on Metal and Slag (No. 1 and 2)																			
	Slag rolling and Carbide at this point		(No. 1)	0.42	0.43	0.02		0.032	0.60		0.07	0.064 (No. 2)	17.7	51.5	11.7	0.118	0.085	0.67	10.4	0.69
1:30	Spec. test on Metal and Slag (No. 3 and 4)																			
	Slag slightly thick and carbide—made addition of spar.	30		0.44	0.46	0.02		0.022	0.62		0.09	0.020 (No. 4)	18.9	51.9	10.7	0.06	0.07	0.26	9.9	0.93
1:30	No. 2 Carbon test		(No. 3)	0.42																
1:35	V_2O_5 charged on reducing slag	35																		
2:00	Electrodes in bath ½ min.																			
2:05	Charged Wash Metal	200																		
	ferro chrome (5 pct C)	86																		
2:10	Charged ferro-silicon (50 pct Si)	130																		
2:20	Charged ferro-manganese (7 pct C)	67																		
2:30	Spec. test on metal and slag. (No. 5 and 6)																			
	Slag was slightly thick, non-rolling, carbide. Poured easily.		(No. 5)	0.51	0.78	0.31		0.010	0.90		0.15	0.015 (No. 6)	18.7	46.7	16.4	0.06	0.1	0.21	8.3	1.14
2:32	Aluminum to bath. 5 lb	4																		
2:40	Tap temperature = 1582°C																			
Total time heat—4 hr 10 min.	Final Analysis		(No. 1)	0.52	0.70	0.32	0.019	0.009	0.92	0.05	0.17									
19–10 in. ingots, 22 × 10 in. butt. 1050 lb each			(No. 2)	0.53	0.71	0.31			0.92		0.17									
McQuaid-Ehn Grain Size—7.																				

the steel determines to a large extent the amount of silica in the slag button or slag patch, and that silica contents of 45 to 50 pct are obtained with manganese to silicon ratios of about unity; and furthermore as the manganese to silicon ratio increases, the amount of silica in the slag button or slag patch decreases, and consequently the viscosity of the slag wash becomes less and will elongate on rolling without shattering.

Part 3 will consider in detail the data of Körber and Oelsen[2] and J. White[3] on equilibrium between silicate slags containing FeO and MnO and molten steel containing Mn, Si, and FeO in solution. The dissociation constants of $FeO.SiO_2$, $MnO.SiO_2$, and $Al_2O_3.SiO_2$ in liquid acid slags will be evaluated through a range of temperatures so that equilibrium can be calculated between acid slags containing SiO_2, FeO, MnO and 25 pct Al_2O_3 and molten steel containing Mn, and Si. The calculated acid slag compositions in equilibrium with steels of various composition will then be compared with the actual slag and metal compositions determined by chemical analyses shown in Part 2.

Part I—Effect of Manganese Silicon Balance on the Cleanness of SAE 6150 and SAE 3312 and a 1.00 pct Carbon Deep-hardening Roller-bearing Steel

The effects of furnace, ladle, and pit practices on the resulting cleanness of steel were studied in considerable detail through a number of years before the manganese-silicon balance was tied down as a source of nonmetallics in the steel. These studies on furnace and pit practice showed that a relatively small effect on cleanness could be definitely tied up with furnace practice. For instance, cleaner steel can be obtained in the SAE grades using slags which deoxidize the metal to a greater degree before metallic deoxidizers (silicon and manganese) are added to the bath. These slags are of low carbide content and are worked on the "wet" side by the use of spar, so that the melter can pour a spoonful of slag and not have to dump it out. High aluminum additions for grain-size control were found to lead to nonmetallic stringers, and the furnace practice was adjusted so that the minimum of aluminum was added to give grain size test rating of about 7 in SAE 6150. High tapping temperatures were known to give cleaner steel, but there is a limit to the height temperatures can be carried because of obvious effects on furnaces, nozzles, stopper rods, and mold life. Heats of the SAE 6150 type are generally tapped at 1580 to 1600°C, and heats of the SAE 3312 type are tapped at 1600 to 1615°C.

Fast pouring times were found to help the cleanness of the resulting ingot. The heats to be discussed here in detail for the SAE 6150 and 3312 types were cast in 1000-lb ingots measuring approximately 10 in. sq at the top, 8¾ in. sq at the bottom, and about 46 in. high. The pouring time for this size ingot was finally set at 55 to 60 sec from start of pouring the ingot to the shut-off at the bottom of the hot-top.

Table 1 shows a typical log of one of these heats of SAE 6150, showing complete steel and slag analyses throughout the melting process.

After several heats of SAE 6150 were made according to the furnace, ladle, and pit practice summarized in Table 1, the effect of the manganese-silicon ratio upon cleanness became apparent on steel rated by step-down tests rolled from pilot bars. The pilot bars represented two tops, one middle, and two bottom billets from each heat. The billet stock in all cases was disc inspected before pieces were cut for rolling to 1½ in. rd. bars. Step-down tests representing steps of ⅛ in. off the diam, and ¼ in. off the diam were turned on these rolled bars. The length of each step was approximately 4 to 5 in. in all cases.

In order to rate numerically a heat of steel in terms of its step-down inspection it is convenient to give some numerical weight to the different classes of slag-lines. The routine practice on inspection is to designate the length of slag lines by five classes, and to assign a numerical weight to each of the various classes to penalize the longer slag lines. This system is as follows.

Class	Length of Lines	Numerical Weight
1	Up to ⅛ in.	1
2	⅛ to ¼ in.	2
3	¼ to ⅜ in.	4
4	⅜ to ½ in.	8
5	Greater than ½ in.	16

This classification for frequency and length of slag lines is extended a step further to penalize slag lines which occur in the tops and middles as compared to the bottoms. The first step in using this system of numerically rating a heat for cleanness is to obtain the sum of the number of lines in each class multiplied by their weight factor, and then to further multiply the top and middle sums by 2. The total summation is then divided by the number of steps inspected to obtain the numerical rating of the heat.

This system is illustrated by the following example:

Pilot Bar Inspection . . . 5 in Length 1½ rd. Bars

	⅛ In. Off Diam					¼ In. Off Diam				
	Class 1	2	3	4	5	1	2	3	4	5
Top........	5	2	1	0	0	7	3	1	0	2
Top........	6	3	0	0	0	5	4	0	0	0
Middle......	3	2	0	0	0	2	0	1	0	0
Bottom.....	5	0	0	0	0	4	0	0	0	0
Bottom.....	6	0	1	0	0	5	0	0	0	0

(Average Class) × (Numerical Weight) for Top, Middle and Bottom pilot bars:

Table 2 . . . Magnaflux Rating of SAE 6150, Aircraft Quality

Pilot Bar Inspection, Hardened and Polished

Heat		1st Step ¼ In. Off Diam CLASS					2nd Step ⅜ In. Off Diam.					Numerical Rating per 6 In. Length	Mn	Si	Mn/Si
		1	2	3	4	5	1	2	3	4	5				
A	T	3	0	1	0	0	2	1	1	1	0	8	0.72	0.45	1.65
	T	2	1	0	0	0	2	1	0	0	0				
	M	0	0	0	0	0	1	1	1	0	0				
	B	3	0	0	0	0	1	0	0	0	0				
	B	4	0	0	0	0									
B	T	0	2	0	0	0	0	0	0	0	0	12	0.73	0.40	1.82
	T	2	0	0	0	1	0	1	0	0	1				
	M	4	0	0	0	0	3	0	0	1	0				
	B	1	0	0	0	0	0	0	0	0	0				
	B	0	0	0	0	0	0	0	0	0	0				
C	T	3	0	1	0	0	2	1	0	0	0	10	0.65	0.45	1.45
	T	4	1	0	0	0	2	2	2	0	0				
	M	3	2	0	0	0	2	1	1	0	0				
	B	2	0	0	0	0	0	0	0	0	0				
	B	0	0	0	0	0	0	0	0	0	0				
D	T	3	0	1	0	0	6	0	0	0	0	12	0.72	0.39	1.85
	T	3	0	0	0	0	1	0	0	0	0				
	M	4	4	0	0	0	5	3	0	0	0				
	B	2	0	0	0	0	2	0	0	0	0				
	B	5	1	0	0	0	5	0	0	0	0				
E	T	4	3	0	1	0	4	3	0	2	0	20	0.68	0.37	1.83
	T	5	0	2	0	1	10	1	1	0	0				
	M	7	1	0	0	0	2	1	0	0	0				
	B	1	0	0	0	0	2	1	0	0	0				
	B	3	0	0	0	0	0	0	0	0	0				
F	T	2	0	0	1	0	1	2	0	0	0	18	0.75	0.46	1.65
	T	1	3	0	0	2	2	3	2	0	1				
	M	1	2	0	0	0	4	2	0	0	0				
	B	1	0	0	0	0	0	0	0	0	0				
	B	2	0	0	0	0	0	0	0	0	0				
G	T	5	3	0	0	0	3	1	0	0	0	13	0.70	0.37	1.85
	T	7	3	0	0	0	2	0	1	0	0				
	M	8	1	0	0	0	3	1	0	0	0				
	B	3	0	0	0	0	6	1	0	0	0				
	B	11	0	0	0	0	5	0	0	0	0				
H	T	5	1	0	0	0	4	0	0	0	0	8+	0.71	0.38	1.90
	T	4	1	0	0	0	6	1	0	0	0				
	M	2	1	0	0	0	5	0	0	0	0				
	B	5	0	0	0	0	9	0	0	0	0				
	B	0	0	0	0	0	1	0	0	0	0				
I	T	2	0	0	0	0	1	1	0	1	0	12	0.79	0.45	1.75
	T	0	0	0	1	0	1	0	0	0	0				
	M	6	0	0	0	1	2	0	0	0	0				
	B	2	0	0	0	0	0	0	0	0	0				
	B	2	0	0	0	0	1	0	0	0	0				
J	T	3	3	0	0	0	4	1	2	1	0	11	0.74	0.40	1.85
	T	3	2	0	0	0	5	1	1	0	0				
	M	3	0	1	0	0	0	1	0	0	0				
	B	0	0	0	0	0	0	0	0	0	0				
	B	1	0	0	0	0	0	0	0	0	0				
K	T											17	0.74	0.43	1.72
	T	4	2	2	0	0 1	1	2	0	0	0				
	M	5	3	0	0	0	5	5	0	0	0				
	B	5	0	0	0	0 1	5	1	0	0	0				
	B	1	0	0	0	0	2	0	0	0	0				
L	T	1	2	1	0	0	4	8	1	0	1	16	0.72	0.41	1.75
	T	4	0	0	0	0	5	1	2	0	0				
	M	6	1	0	0	0	5	1	0	0	0				
	B	0	0	0	0	1	0	0	0	0	0				
	B	1	0	0	0	0	0	0	0	0	0				
M	T	6	7	3	1	0	16	6	1	0	0	26	0.72	0.41	1.75
	T	8	3	1	1	0	5	9	1	0	0				
	M	13	1	0	0	0	10	3	1	1	0				
	B	5	0	0	0	0	3	0	0	0	0				
	B	10	0	0	0	0	2	0	0	0	0				
N	T	3	0	0	0	0	14	4	2	2	1	24	0.71	0.34	2.10
	T	4	3	0	0	1	4	4	1	0	0				
	M	5	1	0	0	0	4	1	1	0	0				
	B	3	0	0	0	0	2	0	0	0	0				
	B	0	0	0	0	0	2	0	0	0	0				
O	T	6	0	0	0	0	4	0	0	0	0	20.0	0.74	0.32	2.30
	T	1	0	0	0	0	2	2	1	0	0				
	T	2	0	1	0	0	4	3	0	0	0				
	M	9	0	0	0	0	7	3	1	0	0				
	B	12	2	0	0	0	8	2	0	0	0				
	B	1	0	0	0	0	0	0	0	0	0				
(4 in. long steps)															
P	T	5	0	0	0	0	2	0	0	0	0	29.0	0.75	0.34	2.20
	T	5	2	0	0	0	5	3	4	1	0				
	T	3	2	1	0	0	2	1	1	0	0				
	M	7	6	1	0	0	8	2	0	0	0				
	B	8	1	0	0	0	1	0	0	0	0				
	B	6	0	0	0	0	1	1	0	0	0				

Table 2 . . . (Continued)

Heat	1st Step ¼ In. Off Diam CLASS					2nd Step ⅜ In. Off Diam.					Numerical Rating per 6 In. Length	Mn	Si	Mn/Si
	1	2	3	4	5	1	2	3	4	5				
(4 in. long steps)														
Q	T 2	1	0	0	0	0	1	0	1	0	14.5	0.71	0.34	2.10
	T 2	0	0	0	0	2	1	0	0	0				
	T 1	1	0	0	0	5	2	0	0	0				
	M 4	3	0	0	0	6	2	0	0	0				
	B 8	0	0	0	0	3	0	0	0	0				
	B 3	0	0	0	0	2	0	0	0	0				
(4 in. long steps)														
R	T 5	3	3	0	0	5	3	0	0	0	19.0	0.74	0.40	1.85
	T 1	1	0	0	0	0	0	0	0	0				
	T 2	0	0	0	0	3	1	0	0	0				
	M 8	2	0	0	0	3	0	0	0	0				
	B 8	1	0	0	0	4	1	0	0	0				
	B 10	1	0	0	0	10	0	0	0	0				
S	T 11	6	1	3	1	3	1	0	1	1	36	0.73	0.34	2.2
	T 0	0	0	0	0	1	0	0	0	0				
	T 2	0	0	0	1	7	2	1	2	0				
	B 20	0	0	0	0	11	1	0	0	0				
	B 0	0	0	0	0	0	0	0	0	0				
	M 4	1	0	0	1	12	2	3	0	0				
(4 in. long steps)														
T	T 18	1	2	1	0	12	4	2	0	0	61	0.78	0.29	2.70
	T 12	1	2	0	0	0	3	2	1	2				
	T 2	2	1	1	0	4	7	4	0	0				
	B 0	0	0	0	0	0	0	0	0	0				
	B 18	0	0	0	0	3	0	0	0	0				
	M 6	1	0	0	0	13	2	1	2	0				
(4 in. long steps)														
U	T 6	1	1	0	0	6	1	1	0	1	47	0.70	0.30	2.33
	T 1	2	0	0	0	2	1	4	1	1				
	T 11	7	2	2	0	0	3	0	0	0				
	B 4	0	0	0	0	1	0	0	0	0				
	B 1	0	0	0	0	0	0	0	0	0				
	M 11	7	0	0	0	4	1	1	1	0				
(4 in. long steps)														
V	T 5	1	0	0	0	3	1	0	0	0	21	0.73	0.32	2.25
	T 4	2	1	0	0	2	2	1	0	1				
	T 3	2	0	0	0	0	0	1	0	0				
	B 2	0	0	0	0	3	0	0	0	0				
	B 4	0	0	0	0	3	0	0	0	0				
	M 3	2	0	0	0	1	2	0	0	0				
(4 in. long steps)														
W	T 0	0	0	0	0	2	3	0	0	0	24	0.70	0.33	2.12
	T 2	0	0	0	0	1	1	0	0	1	24	0.70	0.33	2.12
	T 1	1	0	0	1	4	3	1	1	0				
	B 5	0	0	0	0	2	0	0	0	0				
	B 2	0	0	0	0	1	0	0	0	0				
	M 3	1	0	0	0	6	2	0	0	0				
(4 in. long steps)														
X	T 4	0	0	0	0	0	0	1	1	0	45	0.73	0.28	2.60
	T 1	0	0	0	0	2	1	3	0	2				
	T 2	4	0	1	2	4	2	2	2	1				
	B 1	0	0	0	0	0	0	0	0	0				
	B 0	0	0	0	0	0	0	0	0	0				
	M 1	0	0	0	0	0	2	1	0	0				
(4 in. long steps)														
Y	T 3	0	0	1	1	1	2	0	1	1	48	0.78	0.31	2.50
	T 2	0	0	1	0	8	0	0	0	0				
	T 4	0	1	1	2	4	0	0	0	0				
	M 2	0	0	1	1	4	0	0	0	0				
	B 2	0	0	0	0	1	0	0	0	0				
	B 4	0	0	0	0	0	0	0	0	0				
(4 in. long steps)														
Z	T 3	1	0	0	0	6	2	0	0	0	25	0.83	0.46	1.80
	T 2	0	0	0	0	1	0	0	1	0				
	T 4	2	1	1	0	2	0	0	1	0				
	M 5	4	0	1	0	7	1	2	1	0				
	B 1	0	0	0	0	3	0	0	0	0				
	B 1	0	0	0	0	0	0	0	0	0				
(4 in. long steps)														
AA	T 4	1	0	0	0	3	1	0	0	0	25.0	0.71	0.33	2.20
	T 4	4	1	0	1	6	2	1	0	0				
	T 4	2	0	0	0	4	1	0	0	0				
	M 7	0	1	0	0	8	0	1	0	0				
	B 7	0	0	0	0	2	0	0	0	0				
	B 2	0	1	0	0	2	0	0	0	0				

	⅛ In. Off Diam	¼ In. Off Diam
Tops......	12	29
Middles...	7	6
Bottoms...	7	5

Rating of heat on basis of a weight of 2 for tops and middles equals 20.

The cleanness ratings of successive heats of SAE 6150 made for the aircraft engine industry in 1939 and inspected on the basis of counting visually the slag lines and rating them according to length are shown in Table 2. Fig 1 shows these step-down ratings of the heats as a function of the manganese-silicon ratio for the heats. Here it is seen that as the manganese-silicon ratio decreases the step-down rating becomes less, that is, the heats become progressively cleaner on the step-down inspection.

The dates of melting and inspection of these early heats of SAE 6150 were about 1939 and 1940, and this practice of working to as high a silicon content as possible was adhered to throughout the war. The manganese was kept on the low side of the chemical limit for this specification, and several heats were inadvertently made using a silicon content of 0.60 pct and a manganese content of 0.70 pct. These heats ran true to form, and were cleaner on step-down inspection in 1½-in. rolled bars.

Recently we have had another confirmation of the effect of the manganese-silicon ratio on the cleanness of rigidly inspected steels made to AMS 6260* which is a modification of SAE 3312. For many years before the war our custom was to melt a proprietary alloy grade similar to SAE 3312 steel to manganese limits of 0.30 to 0.50 pct and silicon limits of 0.25 to 0.40 pct. The SAE limits for 3312 allowed the manganese to be made substantially equal to the silicon content so that the manganese-silicon ratio was approximately unity. When the AMS specifications were set up however, we worked to the upper part of the manganese limits of 0.40 to 0.70 pct because of hardenability requirements and the silicon limits of 0.20 to 0.35 pct, so that a manganese-silicon ratio of at least 1.7 was inevitable, and generally this ratio on actual heats of steel was at least 2.00. From the beginning of manufacture of AMS 6260 it was noticed that the heats were considerably dirtier than our proprietary grade of alloy

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* AMS 6260: C 0.07/0.13 pct, Mn 0.40/0.70 pct, Si 0.20/0.35 pct, P 0.040 pct max., Cr 1.00/1.40 pct, Ni 3.00/3.50 pct, Mo 0.08/0.15 pct.

Table 2 . . . (Continued)

Heat	1st-Step ¼ In. Off Diam CLASS					2nd Step ⅜ In. Off Diam.					Numerical Rating per 6 In. Length	Mn	Si	Mn/Si
	1	2	3	4	5	1	2	3	4	5				
(3 in. long steps)														
AB	T 8	4	0	0	0	5	0	1	0	0	44.0	0.73	0.22	3.30
	T 6	1	1	0	0	5	4	0	0	0				
	T 4	6	2	0	0	7	3	1	0	0				
	M 3	1	0	0	0	4	1	0	1	0				
	B 8	1	0	0	0	13	1	0	0	0				
	B 13	0	1	0	0	12	1	0	0	0				
(3 in. long steps)														
AC	T 14	0	1	0	0	6	1	1	0	0	52	0.70	0.26	2.70
	T 3	0	0	0	0	6	2	1	0	2				
	T 4	0	0	0	0	5	2	0	0	0				
	M 4	1	0	0	0	8	0	1	0	0				
	B 25	0	0	0	0	11	0	0	0	0				
	B 9	2	1	0	0	10	0	0	0	0				
(3 in. long steps)														
AD	T 5	1	0	0	0	1	2	0	0	0		0.70	0.32	2.20
	T 5	1	0	0	0	3	4	0	0	0				
	T 5	0	0	0	0	3	0	0	0	0				
	M 2	0	0	0	0	3	2	0	0	0				
	B 2	0	0	0	0	1	0	0	0	0				
	B 1	0	0	0	0	1	0	0	0	0				
(3 in. long steps)														
AE	T 4	3	2	0	2	1	1	1	0	0	74	0.92	0.25	3.7
	T 3	2	0	1	0	5	2	0	0	1				
	T 4	6	6	0	3	2	0	0	0	0				
	M 9	1	0	0	0	7	2	0	0	0				
	B 5	0	0	0	0	0	0	0	0	0				
	B 2	0	0	0	0	2	0	0	0	0				

similar to SAE 3312 in which the silicon was made about equal to the manganese content.

A cooperative program was arranged with an aircraft engine manufacturer to make two heats of AMS 6260 to limits 0.30 to 0.60 pct for both the manganese and silicon. The performance of these two heats was compared with the performance of previous heats of AMS 6260 made to the high manganese and low silicon limits. All of these heats were of our own manufacture so that complete records were available both in our own inspection department and from the aircraft engine manufacturer's magnaflux reports.

Table 3 shows a typical melting log of AMS 6260, the practice shown being a carryover from the practice used in making SAE 3312 to high standards for cleanness. Tapping temperatures were held to the range 1600/1615°C, and 1000-lb ingots were poured in 55 to 60 sec.

Table 4 shows the Carpenter inspection data on step-down tests on pilot bars where available, and miscellaneous step-down reports taken from random bars on production orders, and also the percentage rejection on magnaflux inspection of knuckle pins in an aircraft engine manufacturer's plant. The same method of rating the heats on step-down tests was used as that described above, except that in the case of production lots no weight could be given top and middle as in the pilot bar inspection. (Here it is to be remarked that previously SAE 3312 was supplied for this part for some length of time, and the losses were consistently in the neighborhood of 5 pct or less on final rejection of this difficult knuckle pin and piston pin inspection. On these heats the manganese was held to about 0.40 pct and the silicon content was in the neighborhood of 0.35 pct.)

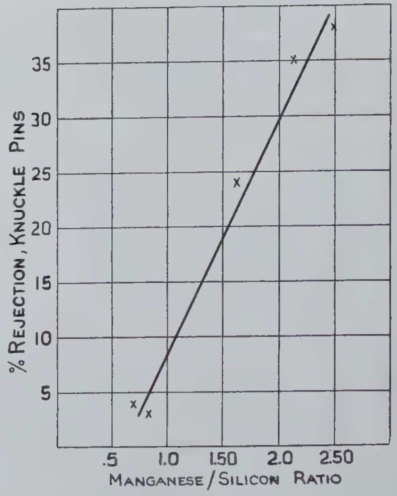

FIG 2—Relationship between Mn/Si ratio heats of AMS 6260 and per cent reduction of aircraft knuckle pins, magnaflux inspection.

Table 4 shows clearly the relation of manganese to silicon ratio on five heats, to both step-down inspection data in our own plant and magnaflux inspection of finished aircraft parts. Fig 2, plotted from some of the data in Table 4, shows the relationship between the manganese to silicon ratio and the percentage rejection of knuckle pins on magnaflux inspection. Here again the conclusion is obvious that the manganese and silicon contents of the heat of steel can exert a large influence on the resulting cleanness of the steel when other operating variables are controlled closely.

An additional example can be quoted

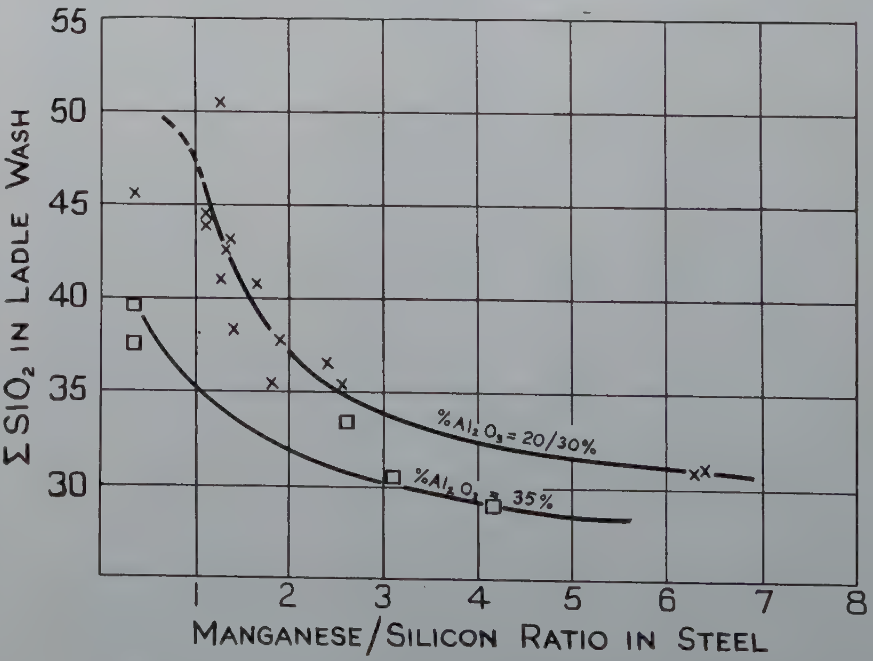

FIG 3—Effect of Mn/Si ratio on the Si content of slag buttons from surfaces of ingots.

to show that the manganese to silicon balance has a large effect on the resulting cleanness of steel when made in the basic electric arc furnace and teemed into ingots from a ladle lined with acid brick. This example has to do with a steel analyzing approximately 1.00 pct C, 1.50 pct Si, 1.50 pct Mn, and 2.50 pct Cr. This steel was developed for the manufacture of large rollers and races which must pass magnaflux testing. The steel previously used analyzed approximately 1.00 pct C, 0.60 pct Si, 1.75 pct Mn and 1.50 pct Cr. When using the latter oil hardening steel the results of hair-line inspection on rollers were very erratic. Some heats were good, but when hair lines occurred they were bad and resulted in rejections of 15 to 50 pct. With the steel containing 1.00 pct C, 1.50 pct Si, 1.50 pct Mn and 2.50 pct Cr, the rejections are uniformly less than 2 pct.

Table 3 . . . Typical Melting Log, AMS 6260

Charge 22,000 lb low alloy nickel scrap and plate. Melted down at 0.25 pct carbon and ored down to 0.036 pct carbon.

9:00 AM..	No. 2 Preliminary test, C 0.036, P 0.020, S 0.028.
9:10/9:25......	Slag-off
9:25......	Slag-on. 400 lb lime, 150 lb spar, 20 lb coke breeze. After slag partly fused added 40 lb 50 pct FeSi (lump) and 100 lb crushed 50 pct FeSi.
9:45......	Back charge 1000 lb high chromium nickel scrap.
10:00......	No. 3 Preliminary test. C 0.048, Mn 0.15, Si 0.12, Cr 1.00 Ni 3.78, S 0.017.
10:35......	No. 4 Preliminary test. C 0.054, S 0.017
11:05......	96 lb FeCr, 33 lb nickel, 20 lb FeMo.
11:15......	115 lb 50 pct FeSi (lump)
11:30......	Preliminary test. S 0.010.
11:45......	5 lb aluminum in bath
11:50......	Tap, tap temperature 1605°C. 3 lb aluminum to ladle.

McQuaid-Ehn Grain Size, 5+

Table 4 . . . Stepdown and Magnaflux Inspection Data on AMS 6260, Aircraft Quality

Heat	Mn/Si Ratio	Weighted Average per 6 In. Length		Pct Rejection on Knuckle-Pin Inspection
		Production Orders	Pilot Bars	
A	1.62	15.6		24
B	2.48	21.6		38
C	2.12	24.0		35
D	0.69	7.0	14.4	3.9
E	0.83	8.4	5.3	3.0

Having established the effect of the manganese-silicon balance on the cleanness of steels when made by carefully controlled melting and pit practice, the problem was now to find a logical explanation for this effect.

Part 2—The Effect of the Manganese Silicon Ratio on the Silica Content of Slag Patches on Ingot Surfaces

In the introductory remarks we pointed out the possible effect of manganese and silicon contents of molten steel on the chemical composition of ladle wash, as evidenced by the slag patches commonly found on the surface of the metal as it is rising in the molds. It was suggested that the principal effect of the manganese and silicon content of the steel on the ladle brick and metal interface would be to form a slag whose viscosity, or fluidity, would be determined by this balance of manganese and silicon.

Slag buttons were collected from the surface of ingots, and in some cases from the upper surface of the steel as it was poured in the molds. This investigation was not concerned with any particular grade of steel because the general chemical composition of such slag buttons was desired. Consequently a variety of SAE grades of steel were sampled, in addition to several grades of tool steels.

Table 5 shows analysis of the metal and of the corresponding slag buttons collected from these heats. For the purpose of this discussion it is sufficient to show the total silica, total alumina, total iron as FeO, MnO and Cr_2O_3 composition of these slags.

These slag analyses fall into two groups, first, those having up to about 25 pct Al_2O_3 and second, a few showing approximately 35 pct Al_2O_3. Fig 3 shows the total silica content of these slag buttons as a function of the manganese-silicon ratio of the steel from which they were collected. Two groupings are shown in Fig 3 corresponding to the two Al_2O_3 contents of the slag buttons. Considering first the 25 pct Al_2O_3 group, it is seen that the saturation value for this type of slag approaches 45 to 50 pct by weight, and that the saturation value is rapidly approached as the manganese-silicon ratio approaches unity. At a manganese-silicon balance of 1.5 the silica concentration of these slags drops to 40 pct, and at a ratio of 2.50 the concentration drops steadily to 35 pct. After this the silica concentration drops gradually with increasing manganese to silicon ratios, until in the region of manganese contents of 1.25 to 1.75 pct, with silicon values of about 0.25 pct, the silica concentration is about 30 pct.

The same general conclusions are obtained on the few samples containing approximately 35 pct Al_2O_3. Here the saturation silica concentration seems to be approximately 40 pct, and this saturation value for silica is reached at a manganese-silicon ratio of somewhat less than unity. At a manganese-silicon ratio of unity the silica concentration in the slag buttons is approximately 35 pct, while at a manganese-silicon

Table 5 . . . Composition of Slag Buttons from Surfaces of Ingots

Heat	Grade	Metal Analysis Per Cent							Slag Analysis—Per Cent by Weight					
		C	Mn	Si	Cr	Ni	Mo	V	Mn/Si	SiO_2	Al_2O_3	FeO	MnO	Cr_2O_3
1	SAE 4340	0.39	0.61	0.20	0.70	1.74	0.22		3.05	30.8	31.8	6.6	32.9	1.31
2	4340	0.41	0.70	0.29	0.68	1.83	0.28		2.4	36.5	27.1	3.8	33.7	0.79
3	3140	0.35	0.55	0.21	0.70	1.31			2.6	33.9	32.9	3.9	31.2	0.80
4	TS*	0.89	1.72	0.27	0.11	0.05			6.4	30.8	25.6	6.0	40.5	
5	TS	0.92	0.26	0.16	0.15				1.63	40.6	27.7	8.2	28.1	
6	Band Saw	0.94	0.23	0.09	0.36	0.04			2.7	35.5	31.0	6.9	25.8	1.20
7	Band Saw	0.96	0.22	0.16	0.37	0.06			1.38	38.3	29.1	5.7	25.1	1.02
8	SAE 6150	0.50	0.68	0.50	0.93	0.06		0.21	1.35	43.2	23.9	4.2	25.5	2.88
9	Thread Gauge	0.20	1.38	0.22	0.09				6.3	31.0	25.3	4.8	39.5	
10	SAE 4340	0.38	0.70	0.17	0.75	1.87			4.7	29.0	34.5	5.1	32.9	0.74
11	3220	0.15	0.36	0.33	1.08	1.70			1.09	44.6	18.0	5.36	26.8	4.0
12	4620	0.17	0.46	0.24	0.12	1.85			1.91	37.8	28.6	4.4	28.9	
13	52100	1.03	0.32	0.29	1.44	0.05			1.10	44.1	16.2	8.04	23.2	7.9
14	52100	1.07	0.40	0.32	0.45	0.04			1.25	50.5	20.7	5.1	24.3	1.5
15	52100	1.01	0.35	0.26	1.42				1.35	42.9	22.2	6.2	24.6	5.4
16	3312	0.095	0.37	0.30	1.56	3.54			1.25	42.6	19.4	5.2	25.7	4.7
17	TS	0.50	0.34	0.99	0.11	0.10	0.40		0.34	45.2	8.5	31.9	12.2	1.23
18	TS	0.52	0.34	1.08	0.10	0.09	0.45		0.32	45.2	20.0	17.7	16.5	0.70
19	TS	0.50	0.65	1.92	0.22	0.04			0.34	41.7	22.9	13.9	23.5	
20	TS	0.47	0.35	1.05	0.13	0.14	0.43		0.33	38.6	34.8	8.2	19.4	
21	TS	0.50	0.34	1.03	0.15	0.05	0.43		0.33	37.4	33.4	9.9	19.3	
22	SAE 2515	0.11	0.46	0.26	0.09	4.96			1.75	35.3	34.8	5.4	26.4	

*TS = Tool Steel.

ratio of 3 the silica concentration is approximately 30 pct by weight.

Fig 3 confirms the results of Körber and Oelsen[2] on the saturation solubility of silica in acid slags containing about 25 pct alumina, and other quantities of FeO and MnO. Due to the nature of the sampling in our experiments on these slag buttons, some spread in values is to be expected for the total silica content, but the data do indicate that a saturation value of 45 to 50 pct by weight silica is found in these acid slags containing about 25 pct alumina.

From the behavior of the slags containing approximately 35 pct alumina, it is clear that the saturation solubility of silica is evidently lower in these slags than in the 25 pct alumina series. Only 5 heats were found which showed 35 pct alumina in their slag buttons, and the reason for these heats deviating from the 25 pct alumina type is not known.

For the time being it is well to remember that Herty, Conley and Roger[4] measured the viscosities of slags in the acid slag system FeO-MnO-SiO_2 at about 1550°C. They found that as the silica concentration of the slag approached saturation at this temperature, then the viscosity of the slag increased greatly. Körber and Oelsen[2] found the saturation solubility of silica in slags composed of FeO, MnO, and SiO_2 to be approximately 50 pct by weight at 1600, 1550 and 1500°C. Körber and Oelsen[2] also found the saturation solubility of silica to be 50 pct in slags composed of 25 pct alumina, ferrous oxide and manganous oxide.

Part 3—Calculation of Equilibrium between Liquid Metal and Acid Ladle Brick

The foregoing data relating to the effect of the manganese silicon balance on the resulting cleanness of basic electric arc melted steels, and on the silica content of slag buttons and slag patches on the sides of ingots, have been interpreted qualitatively on the basis that the manganese and silicon contents of the steels have a large effect on the chemical composition of the interface between the molten metal and the ladle brick. As the manganese-silicon ratio in steel becomes unity or less, the steels become cleaner on any test which measures the macroscopic cleanness of the steel, such as the magnaflux or step-down methods. Furthermore, we have shown that as the manganese-silicon ratio becomes unity or less, then the composition of the slag buttons on the sides of ingots becomes such that the silica content is rapidly approaching saturation. From experimental studies on acid slags, we know that the viscosity of such slags increases rapidly as the silica content approaches saturation.

There is another method of attack which can be used to test the hypothesis that the genesis of these slag buttons, and hence the slag lines, is at the metal-brick interface in the ladle, and that is to set up a system to calculate the composition of these slag buttons from the chemical composition of the heat. Such a method can make use of the available laboratory studies which have been made on the equilibrium of molten steel under acid slags. Admittedly the molten steel-brick interface is not at equilibrium in a strict sense of the word, since the interface is continually breaking up into small globules, and a new interface is being formed by reaction of the steel with the brick which contains approximately 65 pct silica, 30 pct alumina, and 5 pct ferric oxide. However, at the temperatures of molten steel in the ladle there is a good chance that the reaction rates are fast enough so that the composition of the interface approximates the equilibrium composition.

Table 6 . . . Silicon-FeO Balanced Reaction in Liquid Steel

Temperature, °C	$[Si] \times [FeO]^2$
1600	7×10^{-4}
1550	2.72×10^{-4}
1500	0.78×10^{-4}

Table 7 . . . Distribution of Free Ferrous Oxide between Slag and Liquid Iron

Temperature, °C	Mol Per Cent FeO in Slag / Pct by Wt. FeO in Metal
1550	85
1575	77
1600	69

The experiments of Körber and Oelsen[2] on the equilibrium of molten steel containing manganese and silicon under acid slags containing FeO, MnO and silica, when the slag is saturated with silica, can be used to calculate* the dissociation constants of ferrous and manganous silicates in acid slags. To do this, it is necessary that a value be known for the solubility product of $[Si] \times [FeO]^2$. The value determined by Körber and Oelsen's[2] data probably represents the best value available at the present time. Their values for this product, expressed in terms of per cent by weight silicon and FeO in solution in liquid steel are given in Table 6.

The distribution ratio of Herty and Gaines[5] showing the free mol pct of FeO in liquid slags divided by the pct by weight of FeO in liquid steel may be expressed as in Table 7.

The relationships of Tables 6 and 7 may be combined to give the product of (Si) × (Free mol pct FeO in the slag)^2 as shown in Table 8.

The experiments of Körber and Oelsen[2] used liquid steel in sand crucibles in which melts of iron, manganese and silicon were allowed to come to equilibrium with acid slags containing FeO, MnO and silica. Since the crucibles were of sand, the slags were saturated with silica. Considering the constitution of the slag phase, we would like to emphasize that the following remarks on the probable molecular constitution of these slags are made in the light of setting up a set of molecular dissociation constants which may or may not have the correct physical meaning. What we plan to do is to obtain a set of molecular dissociation constants for these acid slags which will reproduce Körber and Oelsen's[2] data, and then these constants will be used to calculate the probable equilibrium between acid slags and liquid steel under conditions different from those of the laboratory experiments.

Table 8 . . . Balanced Reaction between Pct Si in the Metal and Free Mol-pct FeO in Slags, and by Pct Weight FeO in Slag if the Number of Mol per 100 G, M, is Known

Temperature,°C	$[Si] \times (FeO)^2$	$[Si] \times \{FeO\}^2$
1550	1.98	$1.06\ M^2$
1575	2.72	$1.43\ M^2$
1600	3.32	$1.73\ M^2$

The constitution of the slags will be FeO, MnO and SiO_2, and the molecular constituents present will be taken to be free FeO, free MnO, free SiO_2, and $FeO.SiO_2$ and $MnO.SiO_2$. The ordinary chemical analysis will yield only the total amounts of FeO, MnO and SiO_2. The amount of free FeO, as distinct from the amount of FeO combined with silica can be obtained by use of the silicon-ferrous oxide solubility product. If the silicon content is known, then Table 8 will give the amount of ferrous oxide present in solution, but uncombined with silica, in the slag. Assuming that the mol percent of free FeO can be converted to percent by weight of FeO (this can be done if the molecular weight of the slag is known), then a subtraction of this value from the total per cent by weight of FeO present will yield the amount of FeO combined with silica.

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* The calculations which follow are similar to those made by H. Schenck, *Physikalische Chemie der Eisenhütten prozesse*, 2, J. Springer, Berlin, 1934. However, different values for the dissociation constants of $FeO.SiO_2$ and $MnO.SiO_2$ are used by Schenck in his work than those which we will presently derive. For this reason, we will show briefly our method of calculating and checking those dissociation constants.

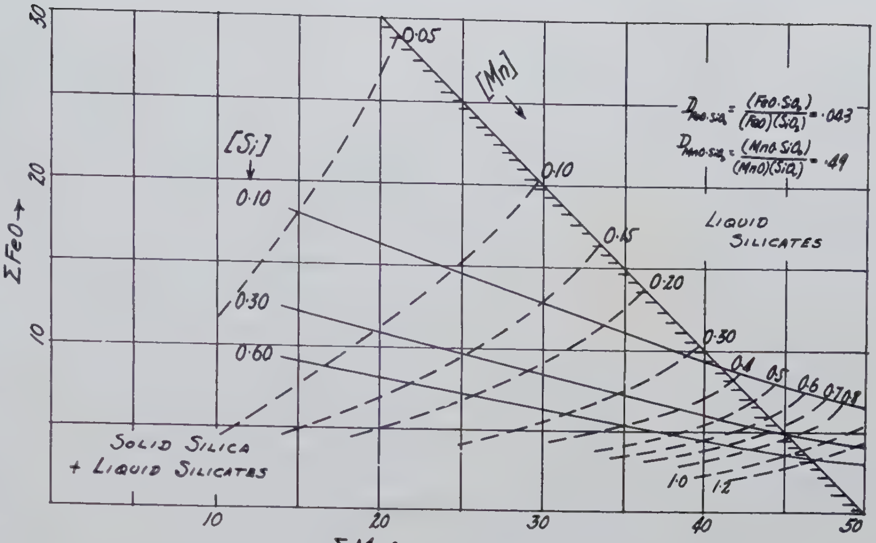

FIG 4—FeO-MnO-SiO_2 slags, 1600°C.

The equilibrium between manganese in liquid steel and free FeO and free MnO in slags is known from the experiments of Krings and Schackmann[6] and Körber and Oelsen.[2] This relationship is of the form:

$$K_{Mn} = \frac{\{MnO\}}{\{FeO\}[Mn]} \qquad [1]$$

and values for K_{Mn} are shown in Table 9. In Table 9 the FeO and MnO quantities refer to weight percent of uncombined FeO and MnO in the slags.

Table 9 . . . Balanced Reaction between Free FeO and MnO in Slags and Mn by Weight in Liquid Steel

Temperature, °C	$K_{Mn} = \frac{\{MnO\}}{\{FeO\}[Mn]}$
1575	2.2
1600	2.0
1625	1.8

Thus, knowing the manganese content of the liquid metal and the free FeO as determined from the silicon content as outlined above, the free MnO content of the slag can be calculated. A subtraction from the total MnO content as determined by chemical analysis will determine the amount of MnO combined with silica.

J. White[3] has published experimental data on the dissociation of $FeO.SiO_2$ in liquid acid slags at temperatures ranging from 1550 to 1625°C. White's data can be represented by the following relationship:

$$\text{Log}\,\frac{(FeO.SiO_2)}{(FeO)(SiO_2)} = \frac{7170}{T} - 5.211 \qquad [2]$$

where the concentrations are in mol percents, and T is the absolute temperature.

When the dissociation constant for $FeO.SiO_2$ is determined from Körber and Oelsen's[2] data as outlined above, it is found that the value is virtually in agreement with White's value in Eq 2. This indicates that White's dissociation constant is consistent with the data of Körber and Oelsen.[2] The dissociation constant for $MnO.SiO_2$ determined from Körber and Oelsen's[2] data as outlined above is

$$\text{Log}\,\frac{(MnO.SiO_2)}{(MnO)(SiO_2)} = \frac{6030}{T} - 3.52 \qquad [3]$$

where the concentrations are in mol percents, and T indicates the absolute temperature.

Equilibrium at 1600°C in the system Fe-Mn-Si-FeO-MnO-SiO_2 may be computed by means of these two dissociation constants, and Tables 6, 7, and 8. These calculations are summarized in Fig 4, where the MnO and FeO contents of an acid slag are shown as a function of the Mn and Si contents of the bath. The shaded line in Fig 4 indicates the saturation value of 50 pct for silica as found by Körber and Oelsen.[2] The balanced manganese and silicon content under an acid slag containing 50 pct silica may be determined by reading the intersection of the Mn and Si lines with this 50 pct silica line. Thus, for 0.30 pct Mn, the corresponding silicon content for 50 pct SiO_2 is 0.09 pct; for 0.50 pct Mn the silicon is 0.15 pct; and for 0.70 pct Mn the silicon is about 0.28 pct. Fig 5, curve *A* shows the experimental Mn and Si contents in liquid steel at 1600°C under acid slags containing 50 pct silica, after Körber and Oelsen.[2] The calculated values determined from Fig 4 are shown as squares, and the conclusion is drawn that these dissociation constants for $MnO.SiO_2$ and $FeO.SiO_2$ reproduce Körber and Oelsen's[2] data over a considerable range of Mn and Si contents.

Körber and Oelsen[2] also determined the Mn and Si contents of liquid steel under acid slags containing 25 pct Al_2O_3 and 50 pct SiO_2 at 1600°C. These data are reproduced in Fig 5, curve *B*. The dissociation constant for $Al_2O_3.SiO_2 = 0.49$ (this is the same value as the dissociation constant for $MnO.SiO_2$ at this temperature) yields the curve shown in Fig 5, labeled curve *C*. Larger dissociation constants for $Al_2O_3.SiO_2$ do not make significant changes in this curve, therefore this is as far as this type of analysis can be carried at the present time to determine the dissociation constant for $Al_2O_3.SiO_2$.

The temperature variation of the dissociation constant for $Al_2O_3.SiO_2$ is taken to be the same as $MnO.SiO_2$.

The equations used at temperatures of 1550 and 1500°C to calculate the composition of acid slags containing about 25 pct alumina as a function of the manganese and silicon content of liquid steel are shown below:

25 pct Al_2O_3-FeO-MnO-SiO_2-Slags at 1550°C*

$$\Sigma FeO = \{FeO\}\left[1 + \frac{0.086}{M}\{SiO_2\}\right]$$

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* In Eq 4, 5 and 6, [ ] refers to weight percentage in liquid steel, Σ indicates the total percent by weight of SiO_2, or MnO, etc. in the slag phase, { } indicates the percent by weight of a molecular constituent, such as free SiO_2, free MnO, etc. in the slag phase, and *M* is the number of mols per 100g when the slag constituents are computed as free FeO, $FeO.SiO_2$, free MnO, etc.

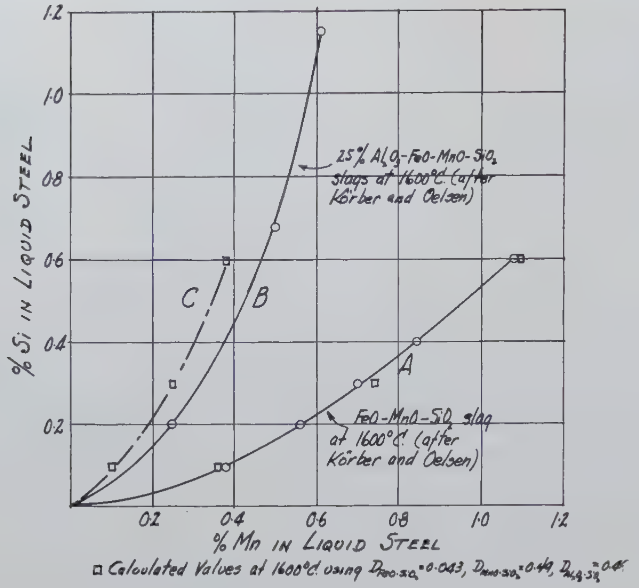

FIG 5—Mn-Si balance at 1600°C in liquid steel under acid slags saturated with silica ($\Sigma SiO_2 = 50$ pct).

$$\Sigma MnO = \{MnO\}\left[1 + \frac{1.00}{M}\{SiO_2\}\right]$$

$$\Sigma SiO_2 = \{SiO_2\}\left[1 + \frac{0.072}{M}\{FeO\} + \frac{0.84}{M}\{MnO\} + \frac{0.60}{M}\{Al_2O_3\}\right]$$

$$\Sigma Al_2O_3 = \{Al_2O_3\}\left[1 + \frac{0.97}{M}\{SiO_2\}\right] = 25 \text{ pct}$$

$$[Si]\{FeO\}^2 = 1.06M^2$$

$$[Mn] = 0.418\frac{\{MnO\}}{\{FeO\}} \qquad [4]$$

25 pct Al_2O_3-FeO-MnO-SiO_2 Slags at 1500°C*

$$\Sigma FeO = \{FeO\}\left[1 + \frac{0.11}{M}\{SiO_2\}\right]$$

$$\Sigma MnO = \{MnO\}\left[1 + \frac{1.26}{M}\{SiO_2\}\right]$$

$$\Sigma SiO_2 = \{SiO_2\}\left[1 + \frac{0.11}{M}\{FeO\} + \frac{1.06}{M}\{MnO\} + \frac{0.76}{M}\{Al_2O_3\}\right]$$

$$\Sigma Al_2O_3 = \{Al_2O_3\}\left[1 + \frac{1.22}{M}\{SiO_2\}\right] = 25 \text{ pct}$$

$$[Si]\{FeO\}^2 = 0.86M^2$$

$$[Mn] = 0.32\frac{\{MnO\}}{\{FeO\}} \qquad [5]$$

Further, the calculated free, or uncombined, alumina in these slags will be about 2.5 pct by weight when calculated according to the above sets of formulas, and the mols per 100 g in the slag will be about 0.93 (M). The free silica can be obtained approximately by

$$\{SiO_2\} = \frac{75 - \{FeO\} - \{MnO\}}{1 + \frac{0.158}{M}\{FeO\} + \frac{1.84}{M}\{MnO\} + \frac{1.5}{M}} \qquad [6]$$

As a sample calculation, let the manganese content of liquid steel in the ladle be 0.70 pct and the silicon content 0.17 pct, and we desire to calculate the total FeO, MnO and SiO_2 contents of the equilibrium slag containing 25 pct Al_2O_3. Take the temperature as 1550°C. Let $M = 0.93$, then

$$\{FeO\} = \sqrt{\frac{0.91}{0.17}} = 2.32$$

$$\{MnO\} = \frac{0.70 \times 2.32}{0.418} = 3.88$$

$$\{SiO_2\} = \frac{75 - 6.20}{1 + 0.39 + 7.70 + 2.06} = \frac{68.80}{11.15} = 6.2$$

$$\{Al_2O_3\} = \frac{25}{1 + 6.48} = 3.34$$

$$\Sigma FeO = \text{Total FeO} = 2.32\,[1 + 0.572] = 3.64$$

$$\Sigma MnO = \text{Total MnO} = 3.88\,[1 + 6.68] = 29.80$$

In terms of mol per 100 g, these are FeO = 0.0505, MnO = 0.4380, Al_2O_3 = 0.3470, and free SiO_2 = 0.103, to give $M = 0.938$. These calculated total FeO and MnO contents of the slag are to be compared with FeO = 5.4 and MnO = 32.9 found experimentally for heat (10) shown in Table 5.

In a similar manner, a broad range of FeO and MnO contents of acid slags containing 25 pct Al_2O_3 and the remainder silica can be calculated as a function of the manganese and silicon content of the liquid steel. These calculations are summarized in Fig 6 and 7 for temperatures of 1550 and 1500°C.

Table 10 shows the predicted MnO and FeO contents in the equilibrium acid slag containing 25 pct Al_2O_3, balance silica slags for the manganese and silicon contents of the heats shown in Table 5. In general the trend is evident that Fig 6 and 7 predict with reasonable accuracy the composition of the slag buttons found on ingots. Considering the fact that equilibrium is

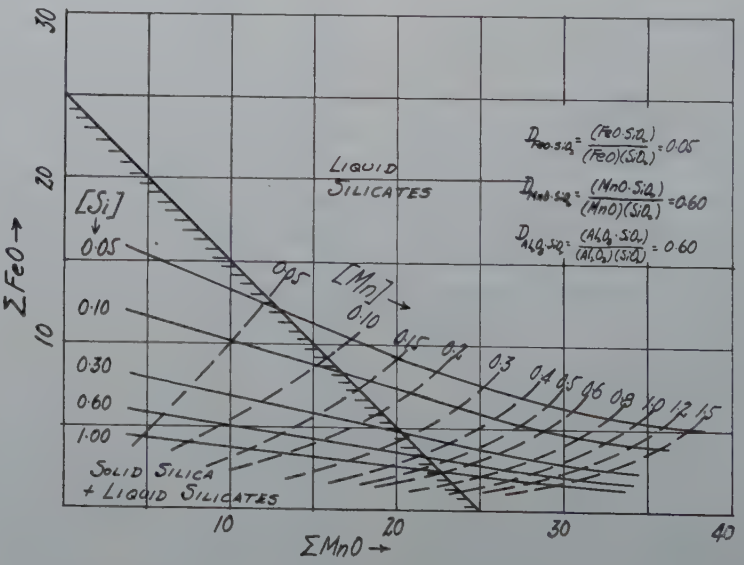

FIG 6—25 pct Al_2O_3-FeO-MnO-SiO_2 slags 1550°C.

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* See footnote on p. 23.

Table 10 . . . Composition of Slag Buttons from Surfaces of Ingots

Heat	Analysis							Slag Analysis				
	C	Mn	Si	Cr	Ni	Mo	V	SiO_2	Al_2O_3	FeO	MnO	Cr_2O_3
1	0.41	0.70	0.29	0.68	1.83	0.28		36.5	27.1	3.8	33.7	0.79
	Predicted slag (1550°C)									3.5	27.5	
	Predicted slag (1500°C)									2.5	29.0	
2	0.35	0.55	0.21	0.70	1.31			33.9	32.9	3.9	31.2	0.80
	Predicted slag (1550°C)									4.0	27.0	
	Predicted slag (1500°C)									3.5	29.0	
3	0.89	1.72	0.27	0.11	0.05			30.8	25.6	6.01	40.51	
	Predicted slag (1550°C)									2.50	35.5	
	Predicted slag (1500°C)									2.0	37.5	
4	0.92	0.26	0.16	0.15				40.6	27.7	8.2	28.1	
	Predicted slag (1550°C)									6.0	22.0	
	Predicted slag (1500°C)									4.5	23.5	
5	0.94	0.23	0.09	0.36	0.04			35.52	31.0	6.9	25.8	1.20
	Predicted slag (1550°C)									7.0	22.5	
	Predicted slag (1500°C)									5.5	24.0	
6	0.96	0.22	0.16	0.37	0.06			38.3	29.4	5.7	25.9	1.02
	Predicted slag (1550°C)									6.5	21.0	
	Predicted slag (1500°C)									5.0	23.0	
7	0.50	0.68	0.50	0.93	0.06		0.21	43.2	23.9	4.2	25.5	2.88
	Predicted slag (1550°C)									3.0	26.5	
	Predicted slag (1500°C)									2.5	28.0	
8	0.20	1.38	0.22	0.09				31.0	25.3	4.8	39.5	
	Predicted slag (1550°C)									3.5	34.0	
	Predicted slag (1500°C)									2.5	34.5	
9	0.38	0.70	0.17	0.75	1.87			29.0	34.5	5.4	32.9	0.74
	Predicted slag (1550°C)									4.5	29.0	
	Predicted slag (1500°C)									3.0	30.5	
10	0.15	0.36	0.33	1.08	1.70			44.6	18.0	5.36	26.8	4.0
	Predicted slag (1550°C)									4.00	22.0	
	Predicted slag (1500°C)									3.5	24.0	
11	0.17	0.46	0.24	0.12	1.85			37.8	28.6	4.4	28.9	
	Predicted slag (1550°C)									4.5	25.5	
	Predicted slag (1500°C)									3.5	27.5	
12	1.03	0.32	0.29	1.44	0.05			44.1	16.2	8.04	23.2	7.92
	Predicted slag (1550°C)									4.5	22.0	
	Predicted slag (1500°C)									3.5	24.0	
13	1.07	0.40	0.32	0.45	0.04			50.5	20.7	5.08	24.3	1.53
	Predicted slag (1550°C)									4.0	23.0	
	Predicted slag (1500°C)									3.0	25.0	
14	1.01	0.35	0.26	1.42				42.9	22.2	6.2	24.6	5.36
	Predicted slag (1550°C)									5.0	23.5	
	Predicted slag (1500°C)									3.5	25.0	
15	0.095	0.37	0.30	1.56	3.54			42.6	19.4	5.2	25.70	4.67
	Predicted slag (1550°C)									4.0	22.5	
	Predicted slag (1500°C)									3.5	24.5	

probably not reached in the glassy brick-metal interface but is approached to some degree before the glassy globules slough off and either rise to the surface of metal in the ladle or are trapped in the stream near the nozzle and carried into the ingot, the calculations are as good as can be expected.

The degree with which the composition of the slag buttons on the surface of ingots melted in the basic electric arc furnace can be calculated, leads to the conclusion that this slag is coming from the ladle and represents globules of the glassy interface between ladle brick and the liquid metal. These compositions were computed on the basis of equilibrium data obtained by allowing liquid steel to come to equilibrium with acid slags in silica crucibles. Thus, the reasonable agreement found between these calculated slags and the composition of the slag button shows that the manganese and silicon contents of the liquid steel in the ladle determine to a large measure the chemical nature of the interface between ladle brick and metal.

Summary and Conclusions

1. Data have been presented to show the effect of manganese and silicon contents of basic electric arc melted steel on the resulting cleanness as measured by the magnaflux test or step down rating for heats representative of SAE 6150, AMS 6260 and a 1 pct carbon, high manganese, high silicon roller bearing grade of steel. These data show that a high manganese content together with a low silicon content of the steel leads to more nonmetallic indications on step-down tests than are present when the manganese and silicon contents are substantially equal. This effect is quite clear on the three grades discussed here, and the effect was apparent when heats were made in succession by fairly rigid control procedures governing the deoxidation practice, refining slag practice, tapping temperatures and pouring times, and using the minimum of aluminum for grain size control. The data apply particularly to basic electric steels melted in 12-ton furnaces and ingot sizes of 10 to 15 in. square (1000 to 2000 lb ingot weight).

2. Experimental data have also been shown which indicate that the manga-

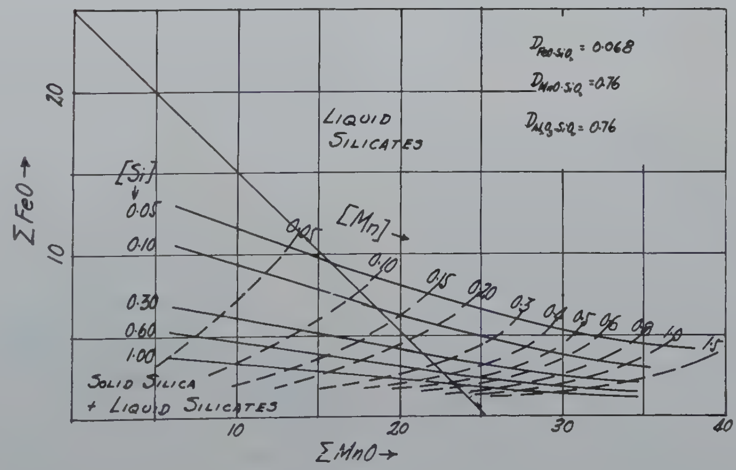

FIG 7—25 pct Al_2O_3-FeO-MnO-SiO_2 slags 1500°C.

nese and silicon contents of the liquid steel, as expressed by the manganese to silicon ratio, do in fact affect markedly the silica content of slag buttons collected from the sides of ingots. Qualitative microscopic data indicate that a large percentage of nonmetallics which cause magnaflux and step-down rejections have the same characteristics as these slag buttons and ladle wash.

3. Detailed calculations are summarized to show that an extension of equilibrium data obtained by Körber and Oelsen[2] in iron melts containing manganese and silicon under SiO_2-FeO-MnO-Al_2O_3 slags accounts reasonably well for the observed slag patch analyses obtained experimentally.

4. A detailed picture of the chemical influence of liquid steel on the physical characteristics of the metal-brick interface is presented in view of the above experimental data. We adopt the outlook that the majority of nonmetallics which are detected by means of macroscopic tests such as the magnaflux test or step-down ratings have their genesis at the interface between liquid steel and ladle brick, and the nozzle. When liquid steel is tapped from a basic electric arc furnace into a ladle lined with brick containing about 65 pct SiO_2-30 pct Al_2O_3-5 pct Fe_2O_3, the brick is first softened or melted at the metal-brick interface. Chemical reactions then take place between the liquid steel and this interface so that its chemical composition approaches that of an equilibrium acid slag containing SiO_2-MnO-FeO and Al_2O_3. The chemical composition of this slag will have a marked influence on its viscosity and hence its ability to resist erosion. For silica contents near the saturation value for such slags, that is about 50 pct SiO_2, coupled with low MnO values, the slag will show a somewhat higher viscosity than would result if the silica content were lower than its saturation value. The data we have shown above in fact represent a study of the influence of the manganese and silicon content of liquid steel on the resulting silica content of this metal-brick interface, as reported by the slag buttons and slag patches from the sides of ingots.

As the steel flows through the nozzle of the ladle the inverse rain of acid slag globules coming from the metal-brick interface in the neighborhood of the nozzle are trapped in the steel and carried down into the ingot mold as the metal is being teemed. These nonmetallics are carried for a considerable distance below the surface of the metal as it rises in the molds, and are swept to the sides and upward as a result of the velocity gradients created in the liquid steel by the force of the stream. The metal is freezing from the sides of the mold inward, and a mushy zone of metal extends for a considerable distance into the body of the liquid steel because of the high rate of heat conduction at the mold wall. Thus these nonmetallics stand a good chance of being trapped in this zone of mushy metal as the ingot is being teemed. Cold metal and slow teeming together or separately will lead to more entrapment of these nonmetallic globules, other conditions remaining constant.

Thus, starting with attention focused on tapping temperatures, pouring times and several operating variables in the furnace, the electric furnace operator can take a large step in cleaning up nonmetallics in such steels by focusing attention on the manganese and silicon balance of the steel. The effect is considerable and can be accomplished easily provided chemical specifications will permit.

5. In view of the above effect of manganese and silicon on the cleanness of basic electric arc melted steel, and the importance of such cleanness in aircraft and specialized alloy steel uses, it is suggested that the engineering societies concerned with steel specifications review the silicon contents of these specifications. Such reviews should be directed toward enabling the steelmaker to balance the silicon content against the manganese content where possible, to take advantage of the effect of these two elements on the resulting cleanness of steel.

Acknowledgment

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The Influence of Temperature on the Affinity of Sulphur for Copper, Manganese, and Iron

E. M. COX,* M. C. BACHELDER,* N. H. NACHTRIEB* and A. S. SKAPSKI*

As a result of using copper-containing scrap in the steelmaking process, the copper content of steels has been steadily increasing for years. Consequently the possible role copper may play in the steelmaking process and in the finished product begins to attract the metallurgists' attention. Some time ago one of the present authors forwarded the idea—based on the results of the analysis of nonmetallic inclusions extracted electrolytically from steels—that sulphur in plain carbon steels is distributed mainly between copper and manganese, the amount of iron sulphide being very small; and that, consequently, the problem of copper and that of sulphur in steel cannot be treated separately.[1]

At the time of the publication of the quoted paper little was known about the relative affinities of copper and manganese for sulphur at high temperatures except that at moderate temperatures (below 1000°C) the affinity of manganese for sulphur is much greater. To gather more experimental data on this subject, the present authors undertook the investigation of the equilibrium constants of the reactions:

$$2Mn_{(s\text{ or }1)} + S_{2(g)} = 2MnS_{(s)}$$

$$4Cu(s\text{ or }1) + S_{2(g)} = 2Cu_2S\ (s\text{ or }1)^*$$

$$2Fe_{(s)} + S_{2(g)} = 2FeS\ (s\text{ or }1)$$

over a range of temperatures wide enough to establish the dependence of these equilibrium constants on temperature. From the equilibrium constants ($K = 1/P_{S_2}$) the free energy of formation (affinity) can be calculated from

$$\Delta F^\circ = -RTln\ 1/P_{S_2} \qquad [1]$$

where the standard conditions chosen are: 1 atm of sulphur pressure and the activities of condensed components equal one.

The decomposition pressure, P_{S_2}, of sulphur over the respective sulphides is too small to be measured directly, but there is a way of eliminating this difficulty by measuring the equilibrium constant of the reaction between the sulphide and hydrogen. From the latter and from the equilibrium constant of the thermal dissociation of H_2S we then calculate P_{S_2} for the respective sulphide.

$$\begin{array}{l} 2Mn + 2H_2S = 2MnS + 2H_2 \\ 2H_2 + S_2 = 2H_2S \\ \hline 2Mn + S_2 = 2MnS \end{array}$$

The numerical values of the equilibrium constant of the thermal dissociation of H_2S at different temperatures were taken from Kelley's paper, "The Thermodynamic Properties of Sulfur and its Inorganic Compounds."[2]

In previous experimental work published by Jellinek and Zakowski[3] and by Britzke and Kapustinsky[4] the equilibrium constants of the reactions *Metal sulphide* + H_2 = H_2S + *metal* were determined by passing hydrogen, at different rates of flow, over the sulphide, analyzing the resulting H_2S + H_2 mixture and then extrapolating the H_2S/H_2 ratio (which is a function of the rate of flow) to the zero speed of flow, a method necessarily involving considerable uncertainty. In the present work the equilibrium ratio was actually measured instead of being extrapolated. The apparatus is shown in Fig 1.

San Francisco Meeting, February, 1949.

TP 2505 C. Discussion of this paper (2 copies) may be sent to *Transactions* AIME before April 1, 1949. Manuscript received April 20, 1948; revision received Oct. 13, 1948.

Experimental Procedure

The sulphides were prepared by the following methods:

FeS

Powdered iron which had been reduced with hydrogen (ferrum reductum) was mixed in stoichiometric ratio with sublimed sulphur and carefully ground. The mixture was put into an alundum crucible, covered with pure sulphur, and the reaction started by touching the mixture with a glowing iron rod. After the reaction was completed the product (still containing some metallic iron) was again ground with sulphur, put into a Rose crucible, covered with sulphur, and heated in a strong current of pure hydrogen. Analysis of the final product showed 62.46 pct Fe and 36.59 pct S. Theoretical for FeS: 63.53 pct Fe and 36.47 pct S.

MnS

Manganese sulphide (precipitated and carefully washed with distilled water containing H_2S) was dried in a Rose crucible in an atmosphere of H_2S and heated in a current of hydrogen for 2 hr at red heat. The product was then ground and ignited for several hours at 1000°C in a current of hydrogen sulphide. Analysis showed 64.53 pct Mn and 36.63 pct S. Theoretical: 63.15 pct Mn and 36.85 pct S.

Some MnS samples were prepared from metallic manganese and sublimed sulphur by mixing and grinding them and then heating in a current of hydrogen sulphide in an alundum tube.

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* Regardless of the form in which copper sulphide may be found in steel at low temperatures (be it CuS or Cu_2S), the high temperature reactions are concerned only with Cu_2S, CuS being unstable above the temperature of red heat.

* Institute for the Study of Metals, University of Chicago.

[1] References are at the end of the paper.

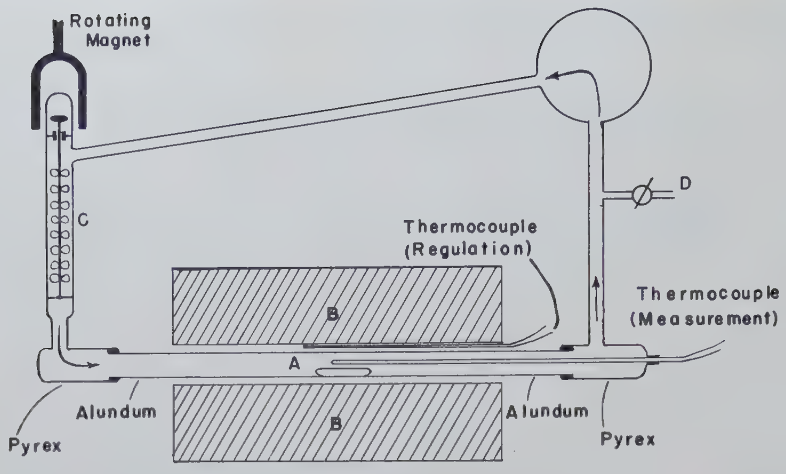

FIG 1—Diagram of apparatus.

No difference was noticed between the MnS samples obtained by the two methods, as far as the value of the equilibrium constants was concerned.

Cu_2S

Reagent grade $CuCl_2$ was dissolved in hydrochloric acid solution and treated with hydrogen sulphide. The precipitate of cupric sulphide was washed with glacial acetic acid and dried at 110°C. It was then placed in a Rose crucible and heated in a stream of hydrogen at 600°C for 30 min. Analysis showed 79.78 pct Cu and 19.68 pct S. Theoretical for Cu_2S: 79.86 pct Cu and 20.14 pct S.

The alundum boat *A* containing a few grams of powdered sulphide (or a mixture of sulphide and the respective metal) was placed in a vacuum-tight tube (quartz, mullite, or Norton Co. RA1164 alundum) about 36 in. long and about 1 in. id, which was mounted inside the furnace *B*; the region of uniform temperature inside the tube was found to exceed the length of the boat by a few inches on each side. The rest of the system was of pyrex glass and was connected to the ends of the furnace tube by means of Apiezon, in the case of the alundum tube. When the quartz furnace tube was employed the connections were by means of graded quartz-to-pyrex seals. When the mullite tube was used, uranium glass was the intermediate in the mullite-to-pyrex seal. The Apiezon connections used for the alundum tube were always kept cool, if necessary by blowing a current of air on them. After the system had been evacuated and checked for tightness, carefully purified hydrogen (tank hydrogen passed through 1:1 KOH, concentrated $KMnO_4$, Pd-asbestos at 500°C, and P_2O_5) was admitted up to atmospheric pressure and the system evacuated again, the operation being repeated three times to insure the removal of any traces of oxygen which might have remained in the system after evacuation. The temperature was then set at the desired level and kept constant by means of a Micromax controller. The thermocouple connected with the Micromax was placed *outside* of the reaction tube while the thermocouple measuring the temperature of the reaction was placed *inside* the tube directly over the boat containing the sample. This arrangement assured a considerable constancy of the temperature inside of the tube, where the variations did not exceed ±1°C. The hydrogen was circulated over the sample and through the system (the total volume of which was about two liters) by means of a magnetically operated glass propeller *C*.

Samples of the gas were taken from time to time through the stopcock *D* with an evacuated 20 ml or 50 ml burette, and the H_2S present absorbed in 2 pct zinc acetate solution. The volume of the remaining hydrogen was measured, temperature and barometric pressure noted and the volume reduced to standard conditions.

The hydrogen sulphide was determined iodimetrically. Either microburettes or 50 ml burettes were used. In the case of the microburettes, the samples were made up to 100 ml with 2 pct zinc acetate solution. An aliquot was acidified with 1.0 ml of glacial acetic acid, titrated with an excess of 0.002 *N* iodine and back-titrated with 0.002 *N* thiosulphate. The 50 ml burettes were used when the hydrogen sulphide content of the sample had to be determined as a whole in one analysis. The procedure was the same with the exception of making up to the volume. In either case, the 0.002 *N* solutions were prepared daily from stock solutions of 0.1*N* iodine and 0.1 *N* sodium thiosulphate, and the sodium thiosulphate was standardized with the 0.002 *N* iodine. The range of hydrogen sulphide content in samples was from 0.015 mg per 100 ml to 1.255 mg per 100 ml. The mean precision was ±3 pct.

The equilibrium was approached from both sides (excess of H_2 and excess of H_2S). The excess of H_2S was obtained in the following way. The equilibrium ratio H_2S/H_2 increases with temperature; therefore, to raise the concentration of H_2S the sulphide was heated in H_2 up to a temperature higher by a hundred or more degrees than the temperature of the intended measurement and, after the equilibrium had been reached, the temperature was lowered as quickly as possible to the intended level.

Fig 2 gives an example of approaching the equilibrium at 900°C from both sides.

The equilibrium with FeS and Cu_2S was usually reached in less than 24 hr. With MnS, however, four to six days were required to obtain equilibrium and, contrary to the behavior of the other two sulphides, high temperature did not reduce the time needed for the equilibrium to be established. In some runs at temperatures over the melting point of Mn, the sulphide sample was examined after the reaction; its grains were covered with a compact layer of metallic manganese. This layer probably contributed to the difficulty of free diffusion of H_2 and H_2S and to the slowness of the reaction at high temperatures.

The reliability of the results would be expected to depend greatly on the suppression of side reactions, especially between the gas mixture and the refractory furnace tube. This was checked by using different tubes (quartz, mullite, and alundum) at temperatures below 1200°C. No notice-

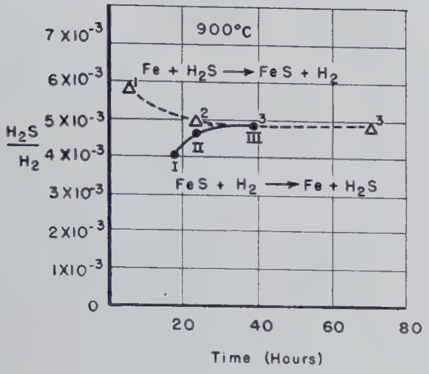

FIG 2—Approach to equilibrium H_2S/H_2 ratio for FeS at 900°C.

able influence of the kind of refractory material used (or of the presence or absence of Apiezon) on the values of the equilibrium ratio H_2S/H_2 was observed. Quartz tubes, however, crystallized and developed leaks. Even the high quality alundum tubes lost their impermeability to gases, especially at temperatures above 1200°C, and many runs had to be discarded because of the diffusion of air into the reaction tube. It is known that the presence of H_2S facilitates the reduction of SiO_2.[5] The silicaceous binding material of the alundum or the silica itself, in the case of quartz, is apparently attacked by this means. Mullite tubes, although they contain silica, withstood the severe conditions to a much better extent than either quartz or alundum. and were used for most of the runs.

Experimental Runs

Table 1 gives a comparison of the log H_2S/H_2 equilibrium values for the reaction $FeS + H_2 = Fe + H_2S$ found by Jellinek and Zakowski, Britzke and Kapustinsky, and in the present investigation. The column "Calc. Kelley" contains Kelley's[2] data, computed from the thermodynamic properties and regarded as quite reliable. It may be seen from Table I that our figures are much closer to those calculated by Kelley than are those of the other authors; the latter, in addition, are in considerable disagreement with one another.

Tables 2, 3 and 4 contain all experimental data for FeS, MnS, and Cu_2S, needed for the calculation of the equilibrium pressure of sulphur over the respective sulphides and of the free energy of formation of these sulphides.

In Fig 3, the values of the logarithm of the equilibrium S_2 — pressure over the sulphides is plotted against $1/T$. The points, though scattered a little, can be represented by straight lines, the slopes of which give the heats of formation of the respective sulphides if we regard this heat of formation (in the first approximation) as independent of the temperature:

$$\log_{10} P_{S_2} = \frac{\Delta H}{2.30RT} + C \qquad [2]$$

To avoid any arbitrariness (due to the scattering of the points) in drawing the lines, the most probable straight lines representing the respective sets of points have been calculated, assuming that the error in $1/T$ was much smaller than the error in $\log P_{S_2}$.

For FeS the measurements were taken up to the melting point of the sulphide. Above this point the activity of the condensed components should be taken into account; this requires the knowledge of the actual composition of the liquid phase at the temperature of the measurement. However, as the study of the reaction with FeS was taken up mainly for the sake of comparison of our data with those of other investigators and for the sake of checking the precision which could be obtained, we did not attempt, for the present, to undertake these measurements.

With MnS the case is different. There is no appreciable solubility of MnS in liquid manganese and therefore the activity of both MnS and Mn remains equal to unity above, as well as below, the melting point of manganese. The scattering of our points is too great to reveal, in a definite way, the effect of phase transitions on the slope of the $\log P_{S_2}$ vs. $1/T$ line. Therefore all points (up to 1583°K) were used in the calculation of the most probable straight line representing them.

The case of Cu_2S is, fortunately, simplified by the fact that, although we have two phases (Cu_2S—rich, and Cu—rich phase) in the liquid state, the mutual solubilities of the components are not very different, and change with the temperature in a roughly similar way. Thus the lowering of the activity of Cu is approximately compensated by the lowering of the activity of Cu_2S and consequently all the points within the whole range of temperatures in question lie on the same straight line.

Table 1 . . . Comparison of the Log H_2S/H_2 Equilibrium Values

T (°K)	Log k (exper.)	Source	Log K (our data)	Log K "Calc. Kelley"
996	−2.10	*	−2.97	−3.08
1003	−2.50	†	−2.93	−3.05
1073	−1.92	*	−2.70	−2.85
1170	−1.73	*	−2.38	−2.61
1183	−2.15	†	−2.35	−2.58
1267	−1.43	*	−2.11	−2.40

* Britzke and Kapustinsky.[4]
† Jellinek and Zakowski.[3]

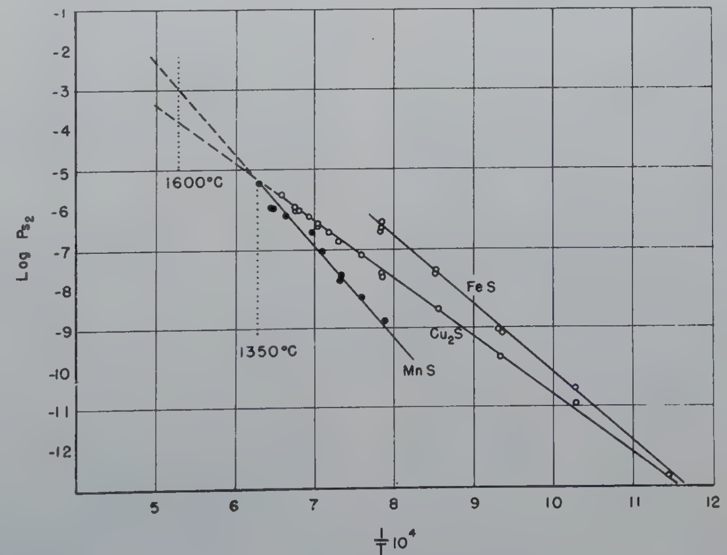

FIG 3—Variation of log P_{S_2} with $1/T$ for MnS, FeS, and Cu_2S.

Table 2 . . . Free Energy of Formation of FeS

T (°K)	$\frac{1}{T} \times 10^4$	$FeS + H_2 = Fe + H_2S$		$2H_2 + S_2 = 2H_2S$	$2Fe + S_2 = 2FeS$	
		$\frac{[H_2S]}{[H_2]}$	Log $\frac{[H_2S]}{[H_2]}$	Log $\frac{[H_2S]^2}{[H_2]^2[S_2]}$*	Log P_{S_2}	Free Energy of Formation of FeS (cal per mol S_2).
770	12.986	4.60×10^{-5}	−4.337	7.127	−15.801	−55,670
873	11.455	2.98×10^{-4}	−3.526	5.690	−12.742	−50,890
973	10.277	1.02×10^{-3}	−2.992	4.582	−10.566	−47,040
1068	9.363	1.97×10^{-3}	−2.706	3.720	− 9.132	−44,620
1073	9.320	2.08×10^{-3}	−2.682	3.675	− 9.039	−44,370
1173	8.525	4.80×10^{-3}	−2.319	2.920	− 7.558	−40,560
1174	8.518	4.15×10^{-3}	−2.382	2.910	− 7.674	−41,220
1273	7.855	9.20×10^{-3}	−2.036	2.285	− 6.357	−37,030
1275	7.843	7.02×10^{-3}	−2.154	2.270	− 6.578	−38,370
1275	7.843	7.25×10^{-3}	−2.140	2.270	− 6.550	−38,210

* All values for log $\frac{[H_2S]^2}{[H_2]^2[S_2]}$ are taken (interpolated) from Kelley's "The Thermodynamic Properties of Sulfur and its Inorganic Compounds."

Discussion of Results

From Fig 3 we see that the intersection of the Cu_2S-line with the MnS-line occurs at 1350°C. At this temperature both MnS and Cu_2S show the same decomposition pressure of sulphur or—what amounts to the same—both Mn and Cu have the same affinity for sulphur (their free energies of formation, $\Delta F° = -RTln\ 1/P_{S_2}$, are the same), provided the activities of the condensed phases are the same. Above 1350°C the decomposition pressure of sulphur over MnS is greater, that is, the affinity of Mn for sulphur is smaller (*ceteris paribus*) than the affinity of copper for sulphur.

The log P_{S_2} vs. $1/T$ lines in Fig 3 can be expressed by the following equations:

for FeS

$$\text{Log } P_{S_2} = -\frac{17{,}810}{T} + 7.540 \quad [3]$$

for Cu_2S

$$\text{Log } P_{S_2} = -\frac{14{,}360}{T} + 3.721 \quad [4]$$

for MnS

$$\text{Log } P_{S_2} = -\frac{21{,}350}{T} + 8.029 \quad [5]$$

Because these equations refer to the reaction between gaseous sulphur and the condensed metal, the heats of reaction between gaseous sulphur and metal (referred to 1 mol S_2-gas) can be directly calculated from them. We then obtain:

for FeS $\Delta H = -81{,}990$ cal
for Cu_2S $\Delta H = -65{,}700$ cal
for MnS $\Delta H = -97{,}860$ cal

Regarding, in first approximation, these heats as independent of temperature we can subtract the heat of evaporation of rhombic sulphur and calculate the heats of reaction between the respective metal and rhombic sulphur, referred to 1 mol of the sulphide. Taking for the heat of sublimation of rhombic sulphur 31,360 cal (from Kelley's paper quoted above) we obtain the following values:

for FeS $\Delta H = -25{,}060$ cal
for Cu_2S $\Delta H = -17{,}170$ cal
for MnS $\Delta H = -33{,}160$ cal

The figures thus found for FeS and Cu_2S are in reasonable agreement with the heats of formation experimentally measured which range from −18,000 cal per mol to −24,000 cal per mol for FeS, and from −18,260 cal per mol to −18,970 cal per mol for Cu_2S. The experimentally found heat of formation of MnS is much more uncertain, the values ranging from −44,390 cal per mol to −62,900 cal per mol. From the aqueous solubility data of MnS[6] a value of ca. −50,000 cal per mol may be calculated. One single point measured for the equilibrium of the reaction $MnS + H_2 = Mn + H_2S$ by Jellinek and Zakowski[5] allowed Kelley to calculate the ΔH of formation for MnS as ca. −35,000 cal per mol. The latter value is the nearest to that obtained by us. On the other hand, the error in the experimentally determined heat would work in the direction of higher values because even a slight oxidation would cause a relatively high heat effect. Therefore lower values seem to be more probable. On the whole, one has to remember that the thermodynamical data for the formation of MnS are still far from being settled.[2]

In Fig 4 the free energies of dissociation of the sulphides per mol of S_2

Table 3 . . . Free Energy of Formation of Cu_2S

T (°K)	$\frac{1}{T} \times 10^4$	$2Cu_2S + 2H_2 = 4Cu + 2H_2S$		$2H_2 + S_2 = 2H_2S$	$4Cu + S_2 = 2Cu_2S$	
		$\frac{[H_2S]}{[H_2]}$	Log $\frac{[H_2S]}{[H_2]}$	Log $\frac{[H_2S]^2}{[H_2]^2[S_2]}$	Log P_{S_2}	Free Energy of Formation of Cu_2S (cal per mol S_2)
972	10.288	6.93×10^{-4}	−3.159	4.600	−10.918	−48,500
1069	9.354	9.55×10^{-4}	−3.020	3.700	− 9.740	−47,600
1071	9.337	9.25×10^{-4}	−3.034	3.690	− 9.758	−47,780
1168	8.562	1.58×10^{-3}	−2.800	2.940	− 8.540	−45,580
1273	7.855	1.92×10^{-3}	−2.717	2.285	− 7.719	−44,920
1273	7.855	2.07×10^{-3}	−2.684	2.285	− 7.653	−44,420
1317	7.593	2.76×10^{-3}	−2.559	2.048	− 7.166	−43,140
1369	7.305	3.03×10^{-3}	−2.519	1.780	− 6.818	−42,660
1393	7.179	3.43×10^{-3}	−2.465	1.658	− 6.588	−41,940
1418	7.052	3.90×10^{-3}	−2.409	1.535	− 6.353	−41,180
1421	7.037	3.62×10^{-3}	−2.441	1.524	− 6.406	−41,670
1440	6.945	4.24×10^{-3}	−2.373	1.432	− 6.178	−40,660
1469	6.807	4.18×10^{-3}	−2.379	1.290	− 6.048	−40,600
1477	6.771	4.53×10^{-3}	−2.344	1.260	− 5.948	−40,140
1477	6.771	4.09×10^{-3}	−2.388	1.260	− 6.037	−40,760
1519	6.583	5.15×10^{-3}	−2.288	1.070	− 5.646	−39,220

Table 4 . . . Free Energy of Formation of MnS

T (°K)	$\frac{1}{T} \times 10^4$	$2MnS + 2H_2 = 2Mn + 2H_2S$		$2H_2 + S_2 = 2H_2S$	$2Mn + S_2 = 2MnS$	
		$\frac{[H_2S]}{[H_2]}$	Log $\frac{[H_2S]}{[H_2]}$	Log $\frac{[H_2S]^2}{[H_2]^2[S_2]}$	Log P_{S_2}	Free Energy of Formation of MnS (cal per mol S_2)
1267	7.893	5.68×10^{-4}	−3.246	2.320	−8.812	−51,050
1317	7.593	8.17×10^{-4}	−3.088	2.048	−8.225	−49,520
1361	7.348	1.19×10^{-3}	−2.923	1.820	−7.666	−47,710
1364	7.331	9.95×10^{-4}	−3.002	1.803	−7.808	−48,690
1407	7.107	1.81×10^{-3}	−2.742	1.590	−7.073	−45,500
1460	6.993	2.80×10^{-3}	−2.553	1.480	−6.586	−43,960
1500	6.662	3.08×10^{-3}	−2.511	1.145	−6.167	−42,300
1539	6.498	3.17×10^{-3}	−2.499	0.980	−5.978	−42,060
1547	6.464	3.06×10^{-3}	−2.514	0.946	−5.973	−41,860
1583	6.317	5.40×10^{-3}	−2.268	0.788	−5.324	−38,530

Some runs were repeated at the same temperature and from the tables above the precision of the measurements may be figured out.

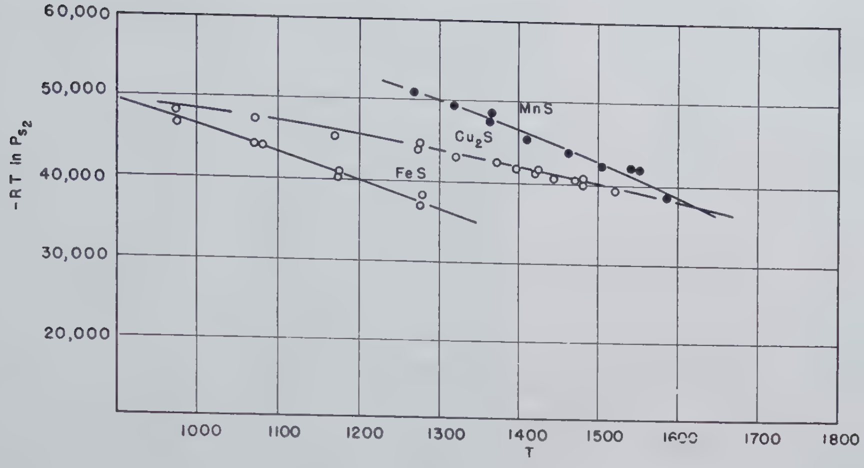

FIG 4—Variation of $-RTln\,P_{S_2}$ with T for MnS, FeS, and Cu_2S.

($\Delta F° = -RTlnP_{S_2}$) have been plotted against T. The slope of the curves $\frac{-\partial \Delta F}{\partial T} = \Delta S$ represents the entropy value, which is negative for the formation of the sulphides. The scattering of the points is too great, however, to make its calculation worth while. At any rate, it is evident from these curves and from the fundamental relationship

$$\Delta F = \Delta H - T\Delta S$$

that the entropy term ΔS for the decomposition reaction $2MnS = 2Mn + S_2$ has a larger positive value than for the reaction $2Cu_2S = 4Cu + S_2$, and is responsible for the relatively lower value of the free energy of the first reaction at high temperatures.

The results of the present investigation lead to the following practical conclusions concerning the connection between the amount of copper in the open-hearth furnace scrap and the sulphur content of the bath. Because of the relatively high affinity of copper for sulphur at high temperatures, metallic copper present in the scrap may be expected to pick up sulphur from the heating gases by binding it into Cu_2S; thus the sulphur content of the bath would increase with the copper content of the scrap and consequently the desulphurization process would be hampered.

The question remains whether the copper sulphide thus formed is preserved as such in the bath and furthermore, whether it still exists in the ingot after solidification. Though the authors are inclined—on the basis of other experiments—to believe that a comparatively large percent of total sulphur exists in finished steel as copper sulphide, they do not think that the present experimental results can be regarded as supporting directly this point of view. Until the equilibrium diagram Cu-Mn-Fe-S and the influence of other components on its shape have been investigated, no further conclusions can be drawn save that the free energy relations of FeS, MnS and Cu_2S in pure systems give a necessary (though not sufficient) support to the possibility of existence of large amounts of copper sulphide in finished steel.

Summary

The equilibrium constants of the reactions of FeS, MnS, and Cu_2S with H_2 were measured within a range of temperature wide enough to establish the dependence of these equilibrium constants on temperature. The equilibrium pressures of S_2 over the respective sulphides and the free energy of formation of the sulphides were calculated therefrom.

The affinity of sulphur for copper (as measured by the free energy of formation of the sulphide) is considerably greater than that for iron and begins to exceed that for manganese at temperatures above 1350°C. It is concluded therefrom that metallic copper which is present in the scrap is to be expected to pick up sulphur from the open hearth furnace gases and thus raise the sulphur content of the bath.

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Plastic Deformation Waves in Aluminum*

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Introduction

One characteristic of plastic deformation which distinguishes it from elastic strain is the essential inhomogeneity of plastic strains. Elastic strain varies continuously through a material, and average relative displacements of initially adjacent atoms are only small fractions of their initial spacing, (strains of the order of 0.01 or less). On the other hand, plastic flow corresponds to the appearance of discontinuities in strain of the lattice, such as dislocations or slip bands, where local strain, on an atomic scale, is several orders of magnitude higher. These discontinuities are visible on a microscopic scale as the familiar slip lines (Fig 1). In spite of this obvious microscopic inhomogeneity, however, macroscopic measurements almost invariably show a smooth curve of stress vs. strain (Fig 2b) even if measurements of linear strains be made to an accuracy of one part in 10^7.

This macroscopic homogeneity of strain indicates that the discontinuities in strain on slip planes occur in increments too small or too slow to be recorded individually, and further that they occur sufficiently independent of one another so that the small increments add at random to a smooth stress-strain curve. The present paper describes observations of plastic strain in aluminum of commercial purity and in high purity Al-Cu alloys, where there exists a strong coupling between slip in various regions of the specimen such that once initiated it spreads rapidly through a large volume. The total effect is that of relatively large, rapid, and regularly spaced steps of strain followed by periods of only elastic strain. Fig 2*a* illustrates the type of "stair-step" stress-strain curve which results. The properties of this cooperative slip phenomenon will be described further in the section on results; in particular it will be shown that each step corresponds to the propagation of a wave of plastic deformation through the specimen. Some interpretations of the mechanism by which it occurs will be made in the following section.

Although the type of plastic wave phenomena to be described has not previously been reported, there are numerous cases of related effects in the plastic yielding of metals:

YIELD POINT PHENOMENA

The most familiar of such effects is the "yield point" observed in low carbon steels, brass, duraluminum, and the like. It consists in the sudden termination of the elastic portion of the stress-strain curve by a large plastic strain. Since the usual tensile machine is such that yielding of the specimen relieves the load, the resulting curve is as shown in Fig 3. As the strain continues, deformation occurs at a lower stress for some time, then follows a rising curve, but with no further sudden yielding. This effect has been observed in brass by Sachs and Shoji[1] and later by many others. Edwards, Phillips and Jones[2] made extensive studies of the effect in steel, and of the role of various alloying elements.

Although there seems to be fairly clear evidence that the yield point is caused by a hardening of the material by precipitation of impurities, no satisfactory explanation for the sudden yielding has been given. Winlock and Leiter[3] have shown that the stress level of the upper yield point depends strongly on the rate of loading, the yield point increasing by almost a factor of two as the strain rate goes from 0.002 in. per in. per min. to 4.4 in. per in. per min. This effect would seem to imply an incubation period before yielding is initiated at a certain stress. On the other hand, by going to very slow loading rates, Edwards, Phillips and Jones[2] showed that the yield point does not become lower and eventually disappear as might be expected, but, on the contrary, begins to rise at loading rates below about 25 lb per in. per min. becoming much higher than at rapid loading rates.

STRAIN AGING

If, instead of continuing straining of a specimen after occurrence of a yield point, the load is removed and the specimen aged, resumption of the test results in occurrence of another yield point as shown by the dotted curve of Fig 3. The new yield stress is generally higher than the previous maximum applied stress. This hardening of the material by straining and subsequent aging is undoubtedly related to quench age-hardening resulting from the aging of a specimen quenched from high temperature. Since neither effect is observed in pure metals, it is generally accepted that quench-aging in all cases is the result of hardening by precipitation of a supersaturated alloying element, and that strain-aging is probably a similar precipitation, accelerated by disruptions of the lattice by previous strain. Pfeil[4] has shown that strain-aging does not occur in iron from which all of the carbon has been removed, but that only a very small carbon content, around 0.003 pct, is necessary to cause strain-aging. In accord with this observation is recent work by Dijkstra[5] in this laboratory showing that the solubility limit of carbon in iron is extremely low, less than 0.001 pct at 400°C. Edwards, Phillips and Jones[2] have shown that the strain-aging effect is also removed by the addition of small quantities of elements such as Mo, Mn, Ti, and the like, which readily form carbides. Their results demonstrate the

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[1] References are at the end of the paper.

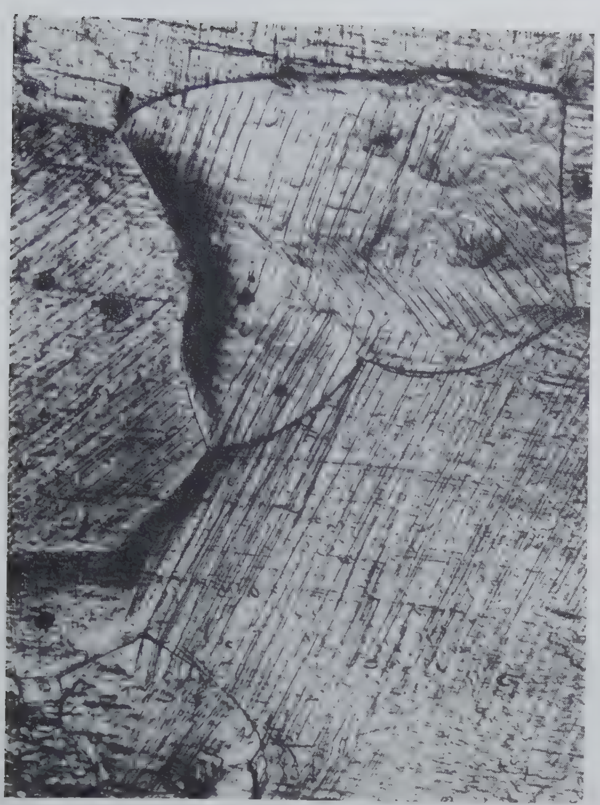


FIG 1—Slip lines in Al-0.5 pct Cu alloy after occurrence of several steps in stress strain curve. Surface electrolytically polished with 2:1 nitric acid methyl alcohol solution prior to straining. Reduced approx. one half in reproduction.

close relation between the yield point phenomena and strain-aging, since both of these effects are destroyed in the same way by addition of carbide forming elements. Their conclusion is that all of the carbon is bound in insoluble carbides and therefore not available for precipitation hardening. Kuroda[6] has suggested that the yield point is caused by concentration of the carbon around the grain boundaries, forming a hard cementite sheath around each grain. When, at the yield point, this sheath breaks down, the stress during further yielding depends only on the ferrite interiors of the grains and is consequently lower (the lower yield point). It appears at present, however, that the yield point and strain-aging effects can be attributed to precipitation of carbon, but that the detailed mechanism of the precipitation hardening is still uncertain.

SERRATED STRESS-STRAIN CURVES

It has been observed that under some conditions the initial plastic portion of the stress-strain curve exhibits no yield point effect, but that after a small plastic strain, a series of sudden yields occurs in rapid succession, resulting in a curve as indicated in Fig 4. This type of behavior has been reported in mild steel from 80–250°C by A. Le Chatelier,[7] in mild steel at 250° by Körber and Pomp,[8] and in duraluminum (Al-4.8 pct Cu) at room temperatures by Portevin and Le Chatelier.[9] More recently Sutoki[10] reported similar observations of serrated curves for steels up to 0.9 pct carbon at temperatures of 150°C and higher, duralumin at 20–100°C, 70/30 brass at 450°, and nickel at 300°. In all of these cases, however, strain was either at a relatively rapid rate, so that the observations were complicated by inertial effects and oscillations of the testing machine, or in a machine such that sudden yielding necessarily decreased the stress.

It is to be noted that the serrated curves occur in the same materials which exhibit yield point and strain-aging effects, but that the temperature ranges for the phenomena may differ. In iron, for example, the serrations occur only in an elevated temperature range, around 200°, whereas the yield point occurs at least as low as 20°. Edwards, Phillips, and Liu[10] therefore expected a yield point in duraluminum at subatmospheric temperatures, since serrations are exhibited at temperatures around 20°. Their tests showed no such yield point, although Sutoki's[10] results show one case of a yield point at room temperature in a quenched and tempered duralumin sample.

LÜDERS' LINES

Lüders[12] reported in 1860 the appearance of large scale markings on the surface of strained mild steel sheet. These markings were later studied systematically by Hartmann[13] and are well known as "Lüders' lines," stretcher strains, or Hartmann or Piobert lines, but are still only incompletely understood. In cylindrical or strip tensile specimens the "lines" appear as broad bands extending completely across the specimen, at angles of around 50° to the axis of tension, and are visible because the greater plastic deformation within the band causes a depression or change in orientation of the surface. The direction of the bands is determined by the geometry of the specimen and the applied stress, and a band may extend across a number of grains, independent of their orientation.

In mild steel specimens, as the yield point is reached, Lüders lines (or bands) appear on the surface and spread throughout the specimen as the yield point elongation takes place. As described by Fell,[14] the spreading takes place at nearly constant stress, corresponding to the horizontal portion of Fig 3, following the yield point, and further strain within the band begins only after the surface markings have spread over the entire surface, at which time the stress-strain curve resumes an upward trend by strain hardening. The surface markings persist, however, presumably because of differences in the amount of yield point elongation in different bands.

Similar effects have been observed in duraluminum by Hartmann[13] and more recently by Fell.[15] Fell shows no photographs of markings in aluminum but describes them as a number of parallel bands (more regular than Lüders' lines in steel) inclined at about 60° to the specimen and tension axis and extending across the strip specimen. A photograph of such bands in 24 ST sheet is given by Stang, Greenspan, and Newman[16] (their Fig 1). Fell also observed that a number of successive yields occurred with increasing stress and in each case an inclined

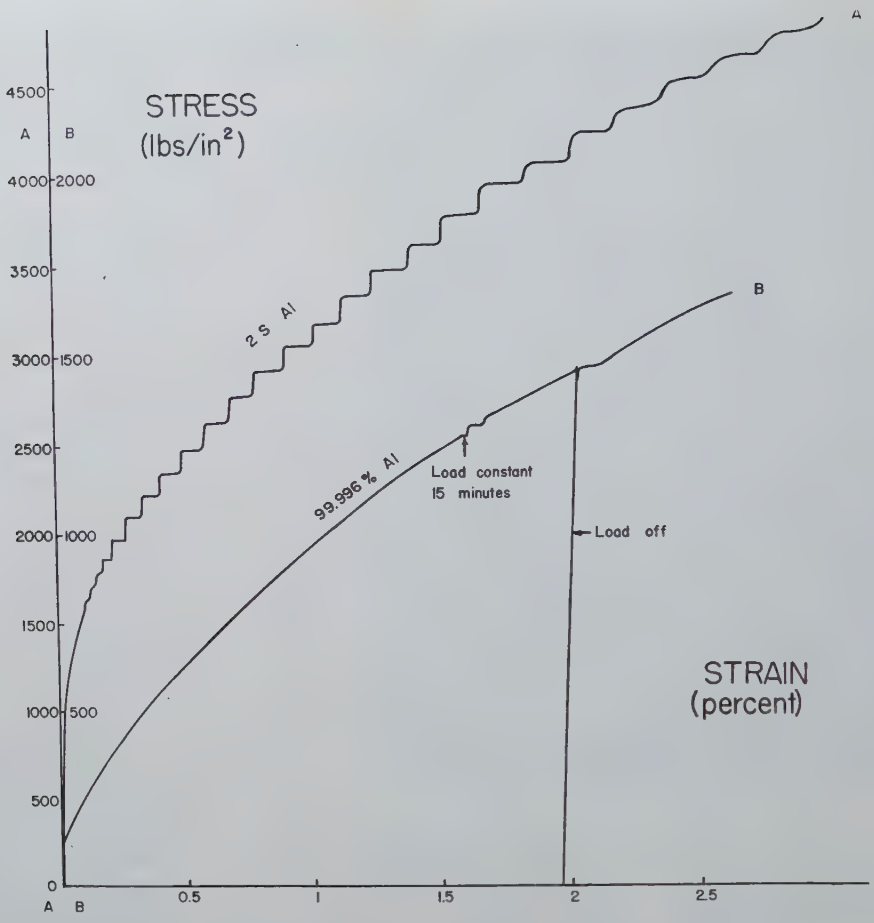


FIG 2—Curves for 0.500-in. diam cylindrical specimens loaded continuously at constant rate of 120 psi per min.

(*A*) Typical step curve for 2S-Aluminum—measured over ¾ in. of gauge length.
(*B*) Smooth curve for pure aluminum under same test conditions. Both removal of load and holding load constant cause slight yield point elongation.

straight line on the surface propagated from one end of the specimen to the other at velocity around 20 cm per sec. Each such yield represented only 0.5–1 pct strain, whereas in steel the yield point elongation is of the order of 5 pct. Portevin and Le Chatelier[9] also reported that the serrated stress strain curves described above were characterized by the appearance of Lüders, lines on the surface and that each oscillation of stress was accompanied by propagation of the markings along the specimen with an audible "little dry noise."

REPEATED YIELDING

A number of cases of repeated yielding have been observed both at constant load and with increasing load.

Becker and Orowan[17] found that zinc single crystals held at approximately constant stress in a Polanyi machine exhibited sharp steps of from 10^{-5} to 10^{-3} strain at irregular intervals, and that a temperature increase of 10–20°C resulted in a great increase of frequency. Schmid and Valouch[18] made similar observations. Measurements of creep rate at constant stress in high purity zinc by Tyndall and Wert[19] showed alternate periods of very rapid and slow creep. Andrade[20] reported sudden yields at regular intervals in "approximately pure" copper under constant stress.

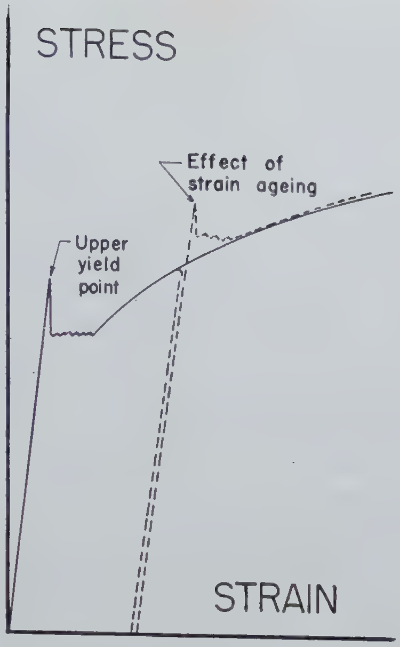
Classen-Nekludowa[21] applied increasing shear loads to specimens of NaCl, brass, and aluminum, and found that yielding occurred in very regularly spaced and sharp steps, resulting in a stair-step type stress strain curve. It was found, however, that these steps occurred only in an elevated and limited temperature range, 230–500°C for NaCl, 410–550°C for brass, and 450–550°C for aluminum. Davidenkow[22] later presented an interpretation of these results in terms of recrystallization.

The relation of the above repeated yield phenomena, at nearly constant stress and at elevated temperatures, to the stair-step stress strain curves observed by the author is not readily apparent. An effect which is obviously closely related, however, is Fell's[15] observation of a number of successive yields of duraluminum strip specimens. The resultant stress strain curve is of stair-step form, similar to those observed by the author. It seems likely also that the serrated stress strain curves shown in Fig 4 would also be in the form of rectangular steps if the loading were accomplished by a machine in which oscillations of stress are precluded.

The effects briefly discussed above: yield point elongation, serrated stress-strain curves, Lüders' lines, and stepped stress-strain curves (repeated yielding), have been arbitrarily divided in the discussion for purposes of clarity. It is desired, however, not to differentiate between them, but rather to point out that all appear to be manifestations of the same effect, propagation of plastic deformation waves through the stressed medium. They have in common that:

1. All involve propagation of plastic deformation
2. The presence of certain impurity atoms in appropriate state of solution of precipitation is necessary
3. The required impurity atoms are those which result in quench or strain age-hardening (C in Fe, Cu in Al, Be in Cu)
4. Appropriate test conditions of temperature and loading rate must prevail, although these conditions may differ for the different effects.

The most plausible general hypothesis seems to be that the effect of the impurity atoms is to precipitate in such a manner as to harden the lattice against plastic deformation, and that such precipitation hardening facilitates propagation of the plastic waves. The present studies on the propagation of successive plastic waves in aluminum were made with the objective of further elucidating both the connection between these related phenomena, and the detailed mechanism by which they occur.



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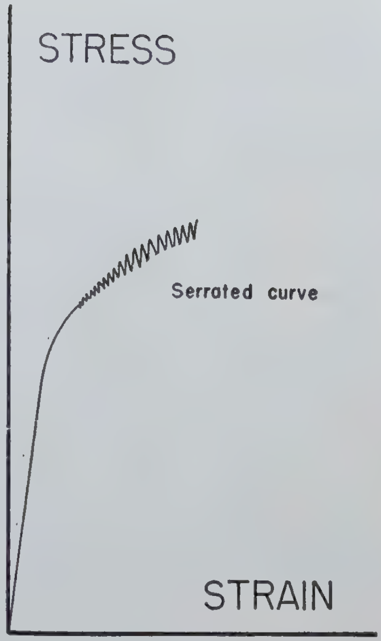

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FIG 3—Illustration of yield point phenomena as found in mild steel. Dotted curve shows effect of aging sample after initial strain.

FIG 4—Illustration of serrated stress-strain curve as found in mild steel at 250° or in duralumin at 20°C.

Apparatus and Procedure

STRAIN MEASUREMENT

The elongation of specimens was measured in all cases electrically by use of bonded resistance wire gauges similar to the commercial SR-4 gauge. Because of such factors as softness of specimens, diversity of gauge sizes and shapes, and necessity of rapid application, gauges were assembled directly on the specimen instead of gluing on commercial SR-4 gauges. The technique used was to glue on a layer of lens tissue with thinned Duco cement and lay on the paper 6 or 8 strands of 0.001-in. diam hard drawn advance wire, of total resistance 100 ohms, held by several coats of the same cement. The ends were then soldered to heavier wires, also glued to the specimen. Gauges of this type usually lasted to about 3 pct strain before the wire broke, and were sufficiently linear over this range. Calibration could be made by measuring specimen length before and after test. Because of softening of the Duco cement, however, these gauges were reliable only up to about 60°C. For higher temperatures the wires were mounted with DC-804 silicone resin supplied by the Dow-Corning Chemical Co. A thin coat of cement was baked on for ½ hr at 200°C; the wires were then laid on and held by a special jig, covered by a second coat of resin and baked another ½ hr. After removal of the jig a third coat was baked on. These gauges were found usable up to temperatures of 170°C, although some relaxing of the resin sometimes occurred, but the useful strain range was only of the order 1 to 1.5 pct.

The gauge constituted one arm of a Wheatstone bridge, with a second arm consisting of a dummy gauge on an aluminum rod in good thermal contact with the specimen, for temperature compensation. The other arms were dial resistance boxes. Current of the order of 25 ma from a storage battery was passed through each arm of the bridge. Instead of the usual null method of using a galvanometer as detector and repeatedly adjusting the resistors for balance, the resistors were left constant and the bridge unbalance recorded continuously on a Brown "Electronik" strip chart self-balancing potentiometer with full scale range of 10 mv. Bridge current was usually adjusted so that full scale on the chart was about 1 pct strain, the smallest detectable strain being about 0.1 pct of the full scale, or 10^{-5} strain, although this sensitivity could be increased about five fold if desired. The chart (see Fig 5) then represented a direct continuous plot of strain vs. time, or, as long as loading rate was constant, strain vs. stress. A chart speed of 30 in. per hr was convenient for most tests, but for rapid strains was increased to 1200 in. per hr, or 0.33 in. per sec.

For measurement of the time relation of strains in different parts of the specimen, four or five gauges were mounted at intervals along its length, each in a separate bridge circuit, and recording each on a separate potentiometer. For these measurements the recorder chart drives were speeded up to 0.33 in. per sec and the four charts were synchronized by periodic electrical pulses.

Since the steps encountered and time intervals between them were in many cases too rapid to be followed by the recording potentiometer, some tests were also made with a 12-channel photographic recording oscillograph with multi-channel amplifier for recording simultaneously the response of several gauges. In this case the bridge current was 5000 cycle ac from an oscillator contained in the amplifier unit, and response time was limited only by the natural frequency (1500 cycle) of the galvanometers. This equipment was kindly made available and operated by Mr. Petersen and Mr. Tahl of the General Motors Electromotive Div.

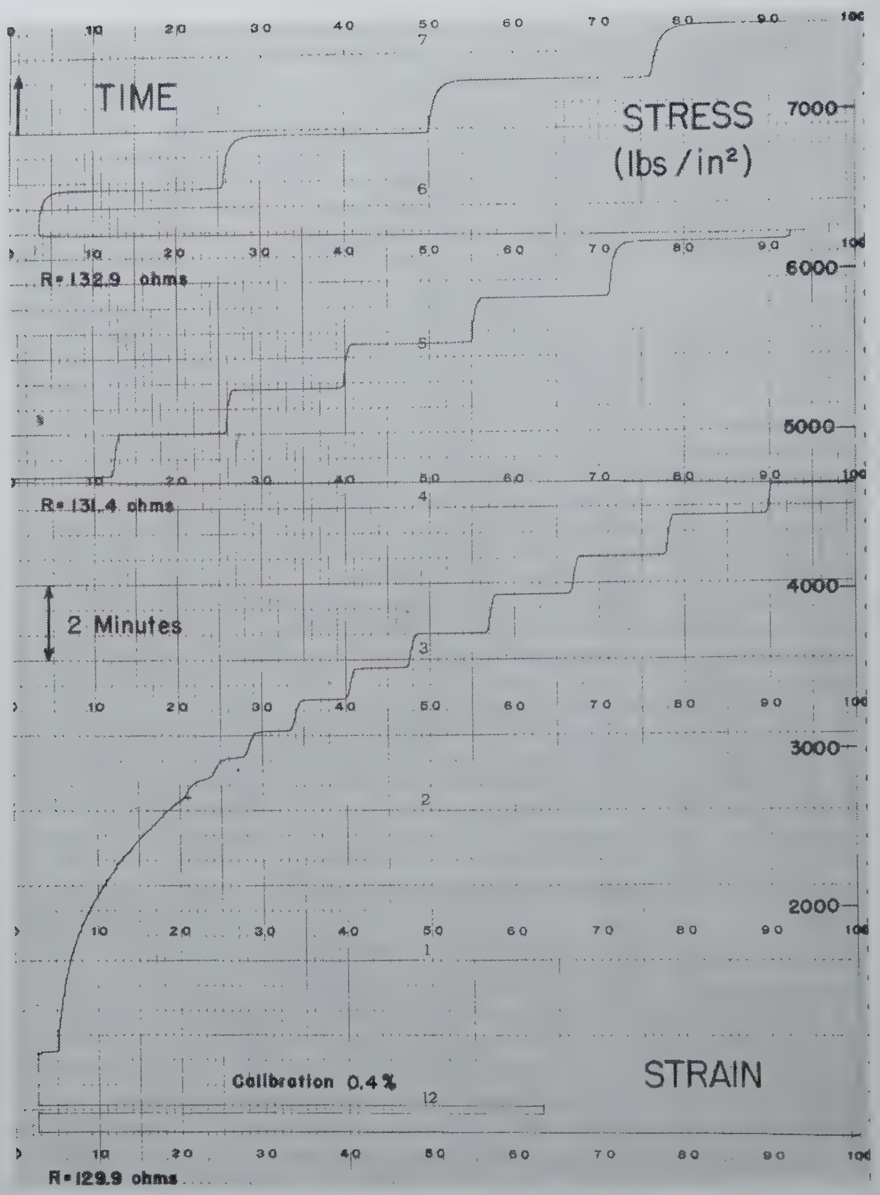

FIG 5—Typical chart record of strain vs. time curve for 2S aluminum at 25°C and continuous loading rate of 240 psi per min. Calibration represents 1 ohm change in one arm of bridge.

Photographic records are shown in Fig. 12.

LOADING APPARATUS

Instead of the standard type of "hard" tensile machine which increases strain at a constant rate, it was desired to have a constant rate of loading (approximately constant stress rate, since strains were small) and to maintain the load during yielding. A simple lever system as shown in Fig 6 was therefore set up. The entire apparatus was on a shock mounted table set on a spring supported concrete block, and the load was communicated to the lever through a soft spring which served the dual purpose of cushioning against external vibration or oscillation of stress during yielding and of measuring the load by its extension. Load could be read to 0.1 mm on the spring scale, corresponding to 0.5 lb on the specimen. It was applied by draining water through a needle valve into a bucket hanging on the spring scale.

The specimens were turned from ¾-in. diam rod to ½-in. diam, leaving a shoulder on each end, and were held in end blocks by a split collar arrangement on which the shoulders rested. Tension rods of ¼-in. steel connected to the end block by a hardened ball and cone socket which allowed self-adjustment to axial stress.

Temperature was controlled by circulating alcohol for low temperature, or prestone for high temperature, through ⅜-in. copper tubing wound around and soldered directly to the end blocks, the liquid being driven by a small centrifugal pump and cooled by passing through coils immersed in liquid nitrogen or a dry ice bath or heated similarly. Temperature differential between end blocks and specimen was always less than 2°C and much less except during rapid cooling or heating.

It is to be noted that the tensile testing procedure used differs from conventional engineering practices in several respects.

1. Load is applied by a dead-weight (soft) type of mechanism rather than by the usual (hard) tensile machine in which elongation is at a constant rate. In such a soft machine stress can be increased at a uniform rate since it is unaffected by yielding of the specimen.

2. The strain-sensitive element measures only a localized area of the specimen rather than averaging over most of the length of the specimen. Also the sensitivity, 0.001 pct, is considerably higher than most mechanical strain gauges.

3. A continuous recording of strain is obtained, as is essential for observing the type of small irregularities which were found in stress-strain curves.

ALLOYS USED

The 2S samples were ordinary commercial ¾-in. rod. Pure aluminum copper alloys were made by melting in vacuum aluminum ingots of 99.996 pct purity, donated by the Aluminum Co. of America, with additions of electrolytic copper shot. The alloys were cast in molds 1¼ × 1¼ × 6 in. and cold rolled to ¾ × ¾-in. square bar, from which specimens were machined. Before testing, each specimen was annealed for ½ hr at 500°C in air and cooled to room temperature in a stream of air. Grain diameter of the resulting structure was about 0.1 mm. Chemical analyses of the samples used are given in Table I.

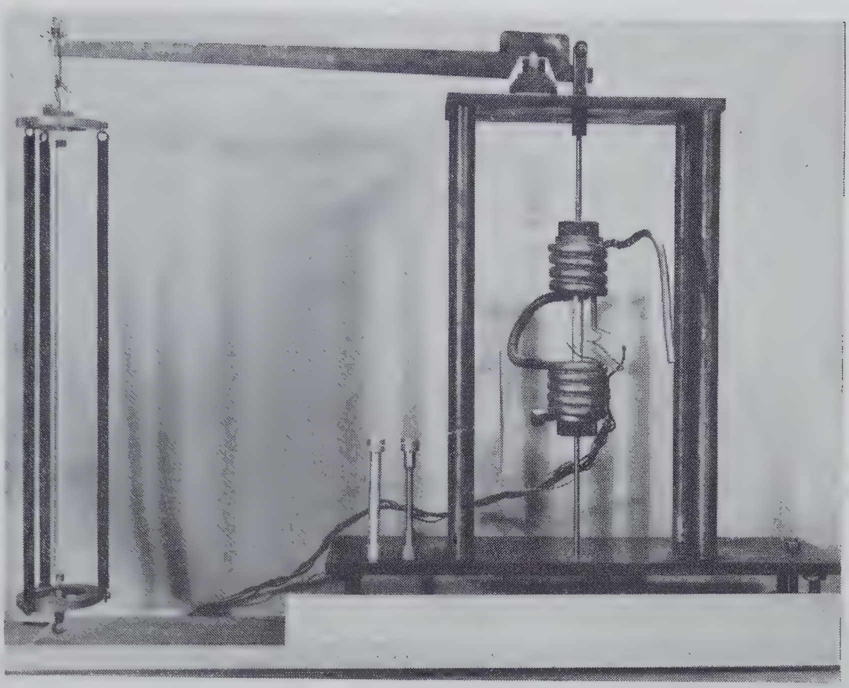

FIG 6—Tensile test machine—constant rate of loading by water flowed into bucket hanging on spring; temperature control by liquid circulating through coils.

Table 1 . . . Chemical Analyses of Samples

Alloying Elements	Alloy				
	A 2S Aluminum Pct	B Al-0.5 Cu Pct	C Al-0.1 Cu Pct	D Al-0.025 Cu Pct	E Brass Pct
Copper	0.14	0.5	0.1	0.025	69.11
Iron	0.48	<0.01	<0.01	<0.005	<0.01
Silicon	0.11	<0.01	<0.01	<0.005	
Zinc					30.80
Lead					0.01–0.1
Cd. As. Bi					<0.01

Results

GENERAL DESCRIPTION OF EFFECT

The general plastic properties have been observed from records of strain by single gauges of ¾-in. length on specimens of 2S and Al-Cu alloys. In an annealed specimen of 2S at 25°C loaded at constant rate of the order of 200 psi per min. the initial portion of the stress-strain curve up to about 0.3 pct plastic strain is smooth. Waves then become perceptible on the record of strain and rapidly become sharper until the curve of strain vs. time assumes a stair-step form with rapid steps of strain (around 0.05 pct) occurring in times of a few seconds and sometimes of 0.1 sec, followed by periods of several minutes during which only elastic extension occurs (see Fig 5). The steps are not random but occur at regular stress intervals of about 250 psi, and adjacent steps represent approximately equal amounts of strain. Actually the spacing and size do not remain constant but become progressively larger with increasing stress, being about proportional to the total stress. Also with increasing stress (or strain) the corners of the steps (in 2S Al) become progressively less sharp (see Fig 10, 14). In Fig 7 the height and length of steps is plotted against total stress.

In view of the differences in technique from conventional tensile testing procedure one test was conducted using an ordinary "hard" tensile machine, which operates at approximately constant strain rate, and which allows relief of stress when the specimen yields. Results (Fig 8) verified that the same phenomena occur, although the sharpness of steps is much decreased.

EFFECT OF STRUCTURE AND CHEMICAL COMPOSITION

Tests under similar conditions, and also over a range of temperatures and strain rates, were also performed on 99.996 pct pure aluminum, which was prepared by the Aluminum Co. of America. Since the pure aluminum in all cases exhibited smooth curves rather than the anomalous curves of the type observed for 2S, anomalies of 2S could be attributed to an effect of the impurity content of the 2S (Cu, Fe, and Si, principally). On that basis copper was chosen as a suitable alloying element and alloys of the 99.996 aluminum with 0.025, 0.1, and 0.5 pct Cu were made up. The observed plastic properties were similar to those of 2S, except that: 1. Steps began at much smaller strains and the first ones are of much smaller size (see Fig 11). 2. Steps are much sharper in 0.1 and 0.5 pct Cu alloys than in 2S. In 0.025 pct alloys the steps are not sharp and appear only under some conditions of previous strain, loading rate, and others. 3. Temperature limits, as discussed below, are different.

The fact that copper content of 0.1 pct is much more effective than

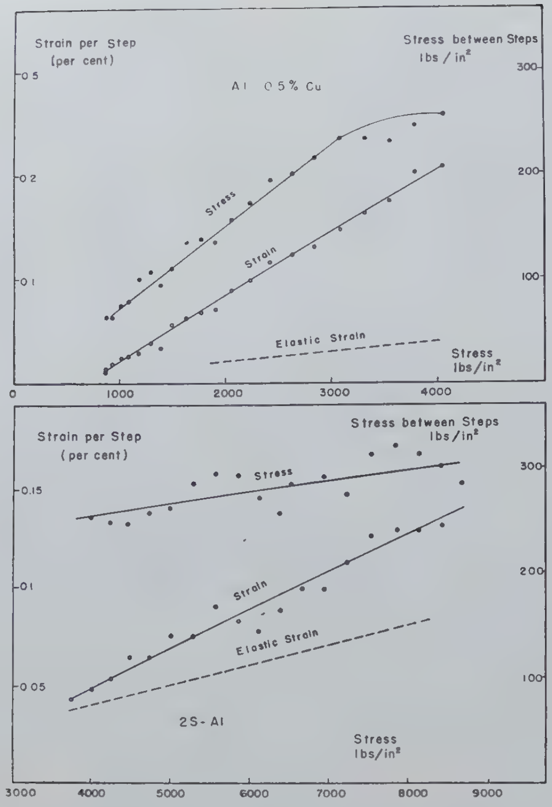

FIG 7—Variation in size of steps with stress. Each curve applies to a single stress-strain curve and each point on curve corresponds to a single step. Horizontal axis is stress at which step occurred.

0.025 pct suggests that the phenomena may depend on precipitation from supersaturated solid solution. Extrapolation of 200–400° data on the aluminum-copper phase-diagram indicates a solubility at 25°C somewhat higher than 0.1 pct, but the solubility limit at this low temperature is rather uncertain. At first it appears surprising that 2S aluminum has less sharp steps than a pure Al-Cu alloy with less Cu content (0.1 pct). It has been shown, however, by Fink, Smith, and Willey[23] that the presence of Fe in Al-Cu alloys greatly decreases their capacity to age-harden, probably by removal of the copper from solid solution. Since Fe is the principal impurity in 2S aluminum, the effective Cu content is thus probably considerably decreased.

Grain size was found to have no profound effect on the qualitative features of the phenomenon although Fig 9 shows that the strength of the alloy is highly dependent on grain size. Note that the step size is greater in the smaller grained structure (where the stress is correspondingly higher) and that the smooth initial portion of the curve continues to greater strains the smaller the grain size.

PROPAGATION

Since continuous plastic flow is observed only until the beginning of the step phenomenon but then ceases, it must be concluded either that the entire region under the gauge remains elastic except for periodic localized slip, or that each step corresponds to a plastic deformation of the entire region, but leaves it in a hard, elastic condition immediately afterward. Simultaneous measurements of several gauges on different parts of the specimen confirmed the truth of the latter supposition.

A large number of tests was made with multiple gauges along the length of the specimen, to investigate the nature and velocity of the propagating plastic deformation wave. The usual arrangement of gauges was four ⅝ in. long gauges in a line parallel to the axis, with ⅛ in. spacing between their ends. Fig 10 shows a typical combined record of four gauges. Although the time differences are barely perceptible on the time scale of Fig 10, steps did not occur simultaneously in all gauges but in rapid succession, and in sequential order. For example, steps would be recorded at intervals of around 1 sec successively on gauges 1, 2, 3, and 4, indicating that strain is initiated at one point and spreads throughout the entire specimen. Thus each step in the stress-strain curve may be considered as the propagation of a plastic deformation wave front along the specimen. It was to be expected that the point of initiation would sometimes lie between gauges and the wave front spread in both directions. It was actually observed that the order of appearance of steps was sometimes, for example, 2, 1, 3, 4, indicating initiation of strain between

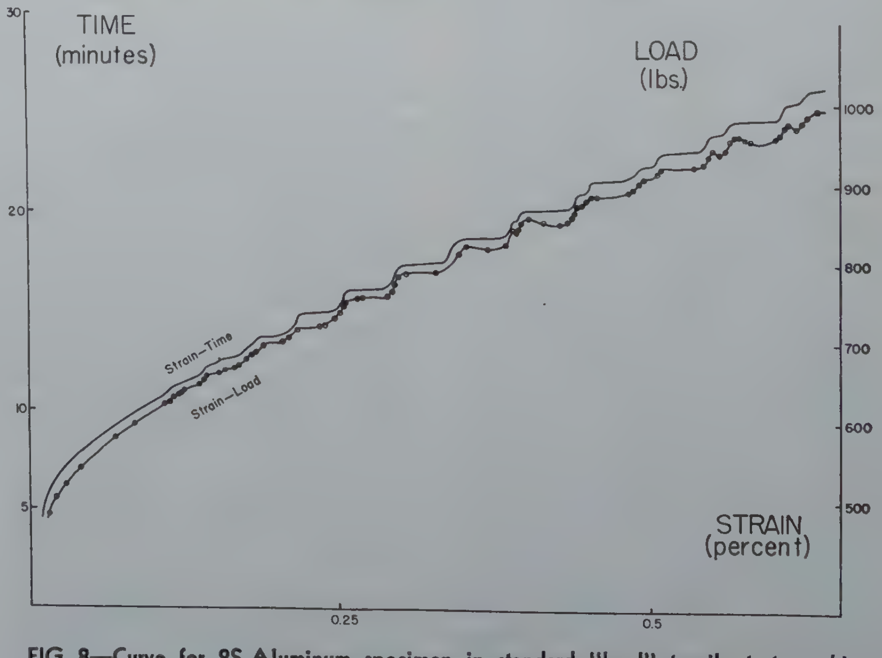

FIG 8—Curve for 2S-Aluminum specimen in standard "hard" tensile test machine. (A) Strain vs. time curve from chart of automatic recorder (B) strain vs. stress curve plotted by combining curve (A) with data read from load dial of machine.

gauges 1 and 2. As strain increased, the steps became more rounded and had no well defined beginning or end (see last steps in Fig 10). Under these conditions it was difficult to distinguish any time difference between strains at different points, and the records showed about the same strain at all four gauges at any instant.

In other cases, however, particularly in Al-Cu alloys, deformation waves propagated only through a limited region of the specimen, then stopped. Strain in the adjoining regions also occurred by the periodic propagation of a wave, but at independent times. This behavior is illustrated in Fig 11. The sharp steps shown occurred at intervals of the order of two minutes, but in every case two or more gauges recorded steps either simultaneously or only a few seconds apart. In Fig. 11 the small numbers beside the four curves indicate relative time in seconds between strain steps which occurred at approximately the same stress. It will be seen that there is a repeated sequential order of occurrence 1–34 . . . 23–4 . . . 1–34 . . . and so on. (See particularly Fig 11 at stresses 2300–3300 psi.) This behavior indicates that each strain propagates through a limited region, that some gauges cover parts of separate regions, as designated by *A*, *B*, *C*, and *D*, and that the sequence of steps in these regions is *A–C* . . . *B–D* . . . *A–C* . . . *B–D*, and so on.

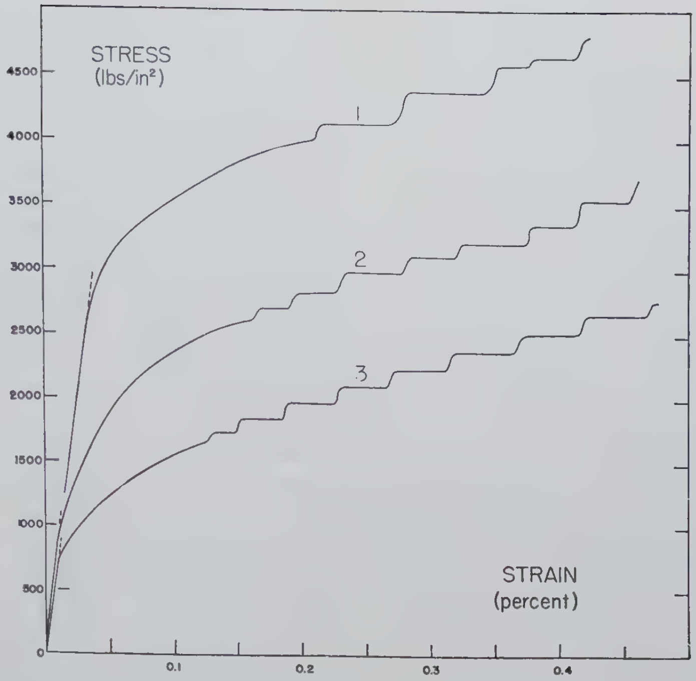

FIG 9—Curves for 2S specimens of different grain size.
Size (1) Grain diam 0.1 mm
(2) Grain diam 1 mm
(3) Grain diam 5 mm (much longer parallel to axis).
Steps begin later but are larger for small grain size.

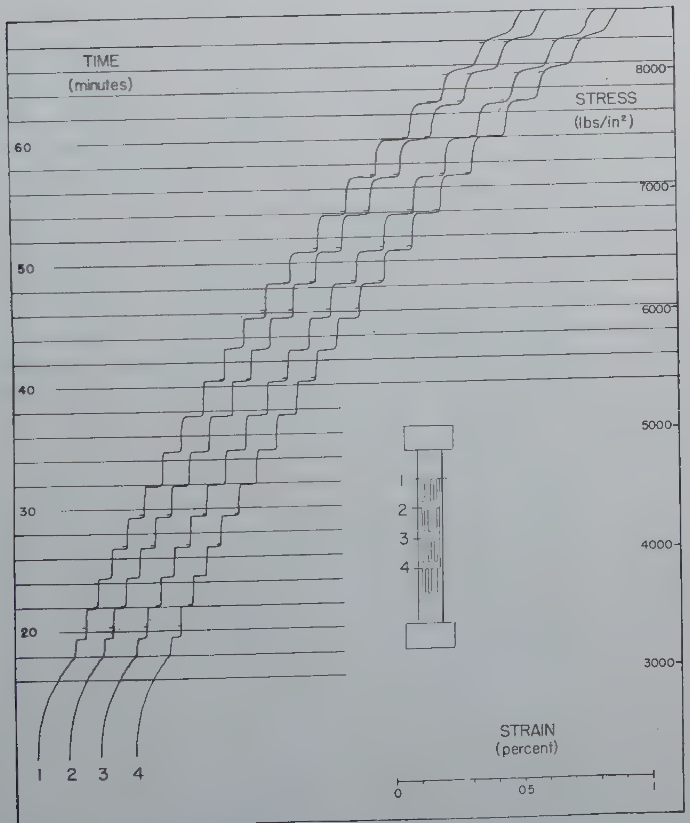

FIG 10—2S Aluminum specimen. Simultaneous records of four gauges arranged as shown along specimen. Sequential order of steps in gauges indicates plastic strain wave starts at one point and propagates through entire specimen.

It can also be seen that appearances of deformation waves in regions *A* and *C* are always within a few seconds of each other, and likewise the times of waves in regions *B* and *D* are very close. The interaction between such separated regions evidently is not by passage of a plastic wave, however, since no strain is registered by the intervening gauge. The nature of the boundaries of the regions is not known, but as seen from the later steps of Fig 11, and as indicated by the dotted brackets, these boundaries are not entirely fixed but shift with increasing strain.

RATE OF PROPAGATION

The propagation velocity of the deformation wave can be measured roughly from its time of arrival at successive gauges. It was found that: 1. The velocity is relatively slow as compared to sound velocities for propagation of elastic waves, being of the order of a few cm. per second. 2. There

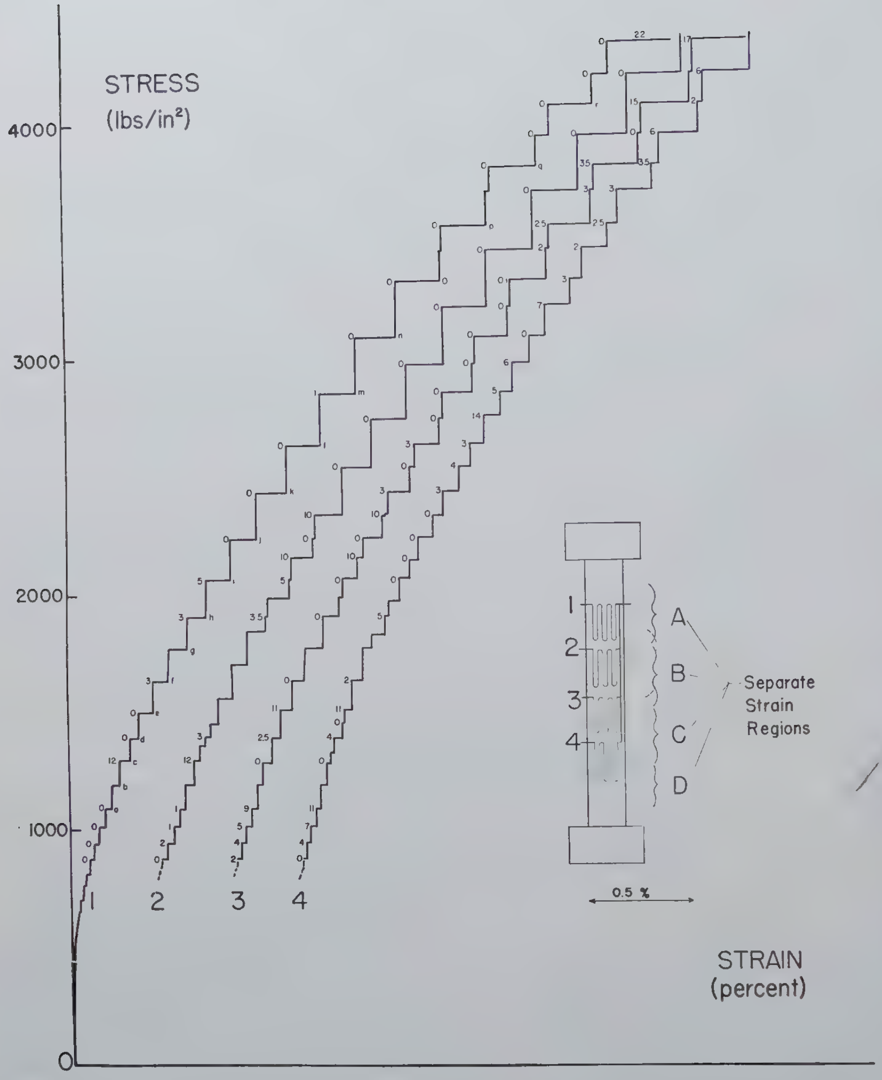

FIG 11—Al-0.5 pct Cu specimen. Simultaneous records of four gauges ½ in. long, ⅝ in. center to center along specimen. Small numbers beside each step give time in seconds relative to other gauges. Analysis of times of steps in various gauges indicates each step corresponds to deformation throughout one of the regions A, B, C, or D.

is no unique velocity for aluminum or even for a particular composition of aluminum, such as 2S, the velocity depending strongly on the state of strain, and varying over a wide range during a single test.

The wide variation in propagation rate is illustrated by Fig 12. In 12*a*, all five gauges, (⅛ in. long and 5/16 in. center to center) show steps in rapid succession at average intervals of about 0.01 sec, corresponding to 80 cm per sec velocity; but in 12*d* the time interval between gauges is of the order of 1 to 1.5 sec, or 0.5 cm per sec velocity. In general it was observed that the rate of propagation was very rapid for the sharp steps observed in pure Al-Cu alloys, all gauges showing steps within a 0.1 sec interval; the rate associated with the less sharp steps characteristic of 2S Al was much less, with intervals up to several seconds between gauges. Under some conditions, however, 2S also exhibited sharp steps, in which cases propagation was rapid. It thus appears qualitatively that the velocity of propagation increases with sharpness, to a maximum of at least 80 cm per sec. This interdependence of sharpness and propagation velocity is partly but not entirely explained by the consideration that a slower wave front takes longer to traverse the gauge and thus results in a less sharp step. Reference again to the last few steps of Fig 10 shows that the steps have degenerated to rounded waves, but, since the waves are almost in phase, the propagation time must be short compared to the duration of a single wave. A sharp but slowly propagating wave would produce a record on which step 1 is completed before 2 starts, and so on.

Considering the plastic deformation of the specimen as a plastic wave progressing through it, it is of particular interest to determine the shape of the wave front, that is:

1. Does the wave front advance continuously, with a smooth transition from zero to maximum strain or in discrete steps by the sudden appearance of strained slabs such as the Lüders' bands in mild steel indicate?
2. Is the wave front a plane surface inclined to the axis and along the direction of maximum shear stress?
3. Is the advancing wave front sharp, and does all of the strain occur immediately as it passes, or persist for some distance and time behind?

Some conclusions on point (3) may be drawn from interpretations of Fig 10–12. It will be noted that in the rapid steps of Fig 12 *a*, *b*, *c*, strain at each gauge continues for about 0.1 sec during which time the wave has propagated to all other gauges and thus a distance of several centimeters. Also the initial part of the step seems more rounded than accountable by time for the wave to traverse the ⅛-in. gauge. Likewise in the slower steps of Fig 10 and 12*d* strain continues at a given point long after the wave front has passed. In Fig 10 the length of the region undergoing strain and the time for which strain continues at a given point are both longer than for more rapid steps as in 12*a*, *b*, *c*. The results then lead to the concept of a continuously moving but not necessarily sharp wave of the type indicated in Fig 13.

Investigation of the plane shape, orientation, or continuity of motion of the wave front cannot readily be accomplished by multiple gauge techniques, first, because a large number of gauges of small area would be required and second, because lack of sharpness of the wave front makes precise time of arrival at a point difficult to determine. For this reason a visual or photographic method seems much more appropriate. Preliminary observations on strip specimens, 0.50 × 0.065-in. cross-section, of 52 S-O aluminum (nominal composition 2.5 pct Mg, 0.25 pct Cr) show plainly visible bands appearing and spreading along the surface. In this case a narrow straight band, inclined 45–50° to the axis, suddenly appears and rapidly spreads in both directions, the advancing boundaries remaining quite straight and at the original orientation. The bands usually do not spread through the entire specimen. In 2S strip, strain waves are accompanied by passage along the surface of a disturbance which is perceptible but not distinct enough to determine its shape, and in Al-0.5 pct Cu no surface markings are seen. These latter results are to be expected since the amount of strain per step is smaller than in 52 S-O, where it is 0.5–1 pct. Even in 52 S-O many steps are recorded by the strain gauge before they increase in size enough to be visible on the surface.

It thus can be considered probable that even in cylindrical specimens the wave front is a plane oriented approximately along the direction of maximum shearing stress. Further work is in progress on visual and photographic observations by improved techniques.

EFFECTS OF TEMPERATURE

By use of a liquid circulating system as described above, temperatures could be controlled within 1°C in the range −60 to 170°C and could be altered within a few minutes without interruption of the test. It was found that the anomalous stepped stress strain curve appears only within a certain temperature range, becoming smooth again above or below that range.

For determination of the upper and lower temperature limits, a series of tests, each on a separate sample and at constant temperature, were made. The results for such a series on 2S aluminum are shown in Fig 14. It will be seen that as the temperature is decreased the step phenomenon begins at greater strains, until at about −20°C the entire curve is smooth except for occasional gentle ripples. On the other hand, increase of the temperature causes the steps to appear at small strains but to fade into a smooth curve, and at sufficiently high temperatures the entire curve is again smooth. Several tests were also conducted in which the temperature was alternately raised or lowered during the course of the test, either while the load was constant, or without interruption of loading. One of these is shown in Fig 14 and is in agreement with the temperature limits indicated by the other curves. Because of the systematic change in the steps with increasing strain, however, this method was not used for determining temperature limits.

A similar series of tests on pure Al-0.1 pct Cu alloy gave a somewhat wider temperature range, but showed that the onset and termination of the steps is much more abrupt in this purer material. Instead of degenerating to rounded waves the steps give way abruptly to a smooth curve. Although the temperature ranges within which the steps occur are not well defined, they can be specified approximately:

Material	Temperature Limits	
	Upper °C	Lower °C
2S Aluminum	+60	−10
99.99 Al + 0.1 pct Cu	120	+10
99.99 Al + 0.5 pct Cu	150	+10

EFFECT OF RATE OF STRESS

Several tests have been conducted with 2S specimens, where, without

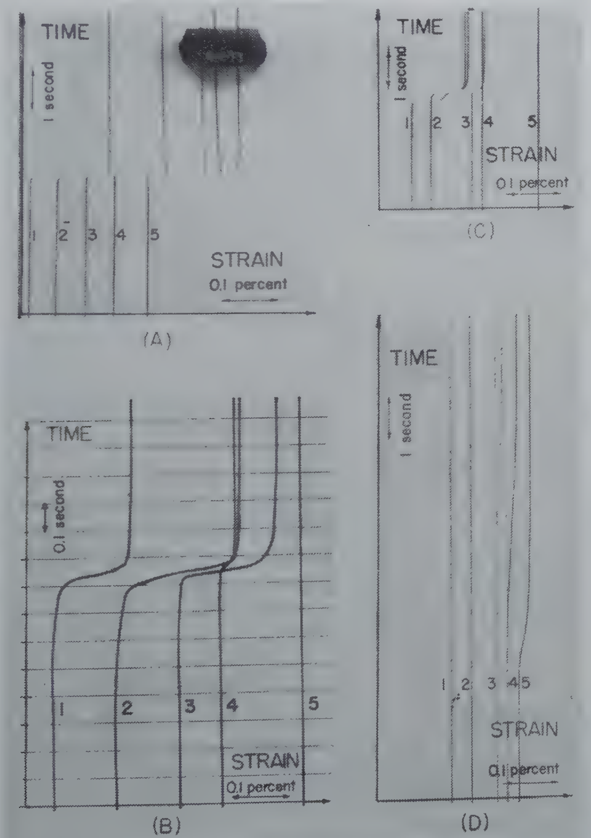

FIG 12—Al-0.5 pct Cu specimen. Oscillograph records of strain at five gauge positions as shown in Fig 13.

(*A*) Strains in rapid 1, 2, 3, 4, 5 sequence as plastic wave traverses specimen in about 0.05 sec.
(*B*) Plastic wave apparently starts near gauge 2 and propagates both ways. Note that strain continues in gauge 2 after wave has advanced to gauge 4, and that wave stops abruptly before reaching gauge 5.
(*C*) Plastic wave in region under gauge 1, then after 0.1 delay wave through region under 1, 2, 3.
(*D*) Slowly propagating wave takes about 1 sec to traverse distance between gauges. Note that rate of strain is correspondingly slow.

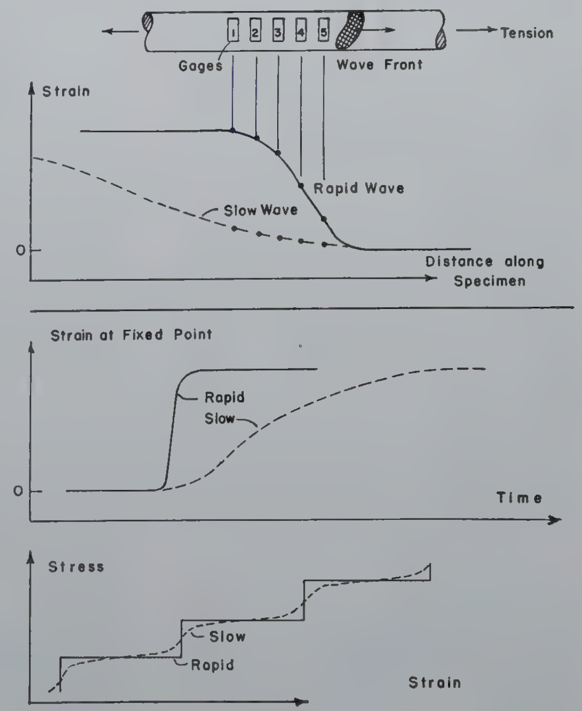

FIG 13—Probable distribution of strain in plastic wave.

As shown, slowly propagating wave has longer duration at a fixed point as a result of both low velocity and greater length. Bottom graph shows stress-strain curve which would result from repeated occurrence of such waves.

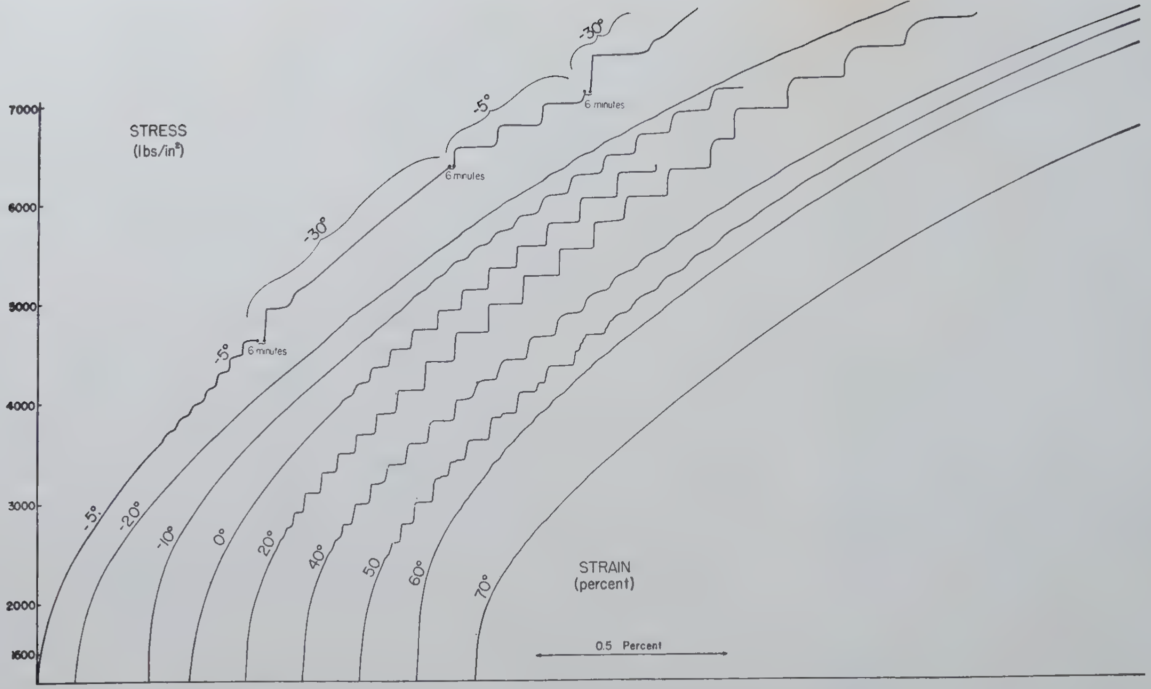

FIG 14—Stress strain curves at various temperatures in 2S Aluminum.
Temperature and loading rate, 120 psi per min, constant in each run, except first curve, where load was held constant for 6 min. during each temperature change.

otherwise interrupting the test, the loading rate has been suddenly changed from slow to rapid rates and vice versa. One of the resulting stress strain curves is shown in Fig 15. It is seen that the size of the steps is affected somewhat, but that variation in loading rate by a factor of 50 causes relatively small changes, less than a factor of 2, in step size and spacing. It is to be expected that the effect of rate may well be much greater near the upper or lower temperature limits, but as yet, the effect of loading rate has been investigated systematically only at room temperature.

In 0.025 pct Cu alloys it is found that steps in the curve appear only under certain conditions. In particular, the rate of loading must be sufficiently slow. This would indicate, in terms of the mechanism postulated in the following section, that with such low copper content, more rapid loading rates do not allow sustained steps because of insufficient time for precipitation hardening between strains.

EFFECT OF AGING AND HEAT TREATMENT

Since the effects observed are shown to depend on the presence of an alloying element in the aluminum and are probably the result of a supersaturated solid solution, appropriate aging or heat treatment might be expected to affect the plastic properties by changing distribution of the solute atoms in solution, or in precipitation aggregates. The stress-strain curves were found to be unaffected, however, by the difference between a water quench from the annealing temperature of 500°C (which should result in maximum supersaturation) and relatively slow cooling from 500°C, followed by 20 hr annealing at 100°C (which should precipitate out the supersaturated solute atoms). Fig 16 shows the result of a test in which straining was interrupted at intervals for heat treatment. Effects of heat treatment were minor.

It has been observed, however, that specimens of 2S aged around 100 days at 25°C subsequent to annealing deform in sharper steps than those freshly quenched.

STEP PHENOMENON IN BRASS

Several other metals have been tested under conditions similar to the tests of aluminum. Cadmium and high purity copper exhibited only smooth curves, but annealed 70/30 alpha brass had a stepped stress-strain curve similar to those described above, with regular steps of around 0.5 pct occurring at stress intervals of around 150 psi. It was observed that the step phenomenon does not set in until strain of a few percent has occurred. If the specimen is given a somewhat smaller strain and aged one or two days at room temperature, however, steps begin immediately when plastic straining is resumed. Otherwise no systematic study of the effect in brass has been made.

Discussion and Interpretation

Before attempting to make interpretations of the physical mechanism of the plastic effects observed, the qualitative general results may be summarized. These results apply to fully annealed cylindrical tensile specimens of 2S aluminum and of aluminum-copper alloys with 0.1–0.5 pct copper, strained at a constant rate of loading.

1. The elastic portion of the stress strain-curve is followed by a gradual and smooth plastic region up to 0.1 to 0.3 pct, followed by a short transition region in which the curve changes to the form of square steps of regular height and width. Subsequent deformation occurs almost entirely by steps, the size of which increase proportionally with the total stress. Some homogeneous creep may occur between steps, accelerating just before appearance of a step.

2. The steps are found to be the result of the initiation of plastic strain

at some region in the specimen and its propagation as a wave of plastic deformation along the length.

3. The plastic waves move at velocities up to a maximum of at least 80 cm per sec, the velocity being greater for sharper steps. They do not necessarily traverse the entire sample but may be stopped by structural barriers of undetermined nature. Plastic flow at a given point continues after the wave front has passed several centimeters beyond.

4. If aluminum free of impurities (99.996 pct pure) is used or if the temperature of test lies either above or below a certain range, −30 to +60°C for 2S, +10 to 120–150°C for Al-Cu alloys, deformation occurs not by the above step process but according to a smooth stress-strain curve.

5. Appearance of the steps is not greatly influenced by heat treatment of either strained or unstrained specimens, although prolonged aging of annealed 2S specimens results in somewhat sharper steps and aging of previously strained specimens decreases the sharpness.

On the basis of experimental results summarized above several postulates can be considered with regard to the physical mechanism by which plastic deformation occurs under these conditions. In this section they will be enumerated and the degree to which they provide an adequate interpretation of observed qualitative features of the phenomena discussed in each case:

1. The presence of alloying elements in aluminum is necessary to harden the lattice against continuous plastic flow between steps. The most probable mechanism by which such hardening is effected is by precipitation of the solute atoms on slip planes.

   a. This postulate is based on the observation that pure aluminum (99.996 pct) exhibits a smooth stress-strain curve under conditions where Al-Cu alloys have anomalous curves.

   b. Precipitation can occur in relatively short times even at room temperature as evidenced by the well known age-hardening effects of Al-Cu alloys. It should be mentioned, however, that extrapolation of higher temperature diffusion rate data would give diffusion rate at room temperature much too low to allow precipitation. It appears therefore that such extrapolation is not valid. In the present case it must be assumed that precipitation is greatly accelerated in the vicinity of slip bands where many lattice vacancies and imperfections exist.

   c. Preferential precipitation on slip bands has been shown metallographically in Al-Cu alloys by Fink, Smith, and Willey.[23]

   d. If hardening is effected by precipitation, the steps would be expected to disappear as the temperature is decreased into a range where precipitation rate becomes too slow. This is in accord with observations that the steps do gradually fade and disappear over a temperature range from 0 to −20°C. (See Fig 14.)

2. Macroscopic steps in the stress-strain curve represent a cooperative effect between grains, by which relaxation on slip bands in one grain initiates slip bands in adjacent grains.

   a. Thus plastic deformation occurs as a wave propagating from grain to grain.

   b. On a larger scale the wave spreads through large regions of the metal, as a front usually extending entirely across the specimen, as observed both visually and by simultaneous recording of strain at several points on the tensile specimens.

3. Initiation of new slip bands in adjacent grains depends on building up of stress concentrations at the edges of slip planes or, viewed on a larger scale, ahead of an advancing deformation wave front. Consequently, under conditions where continuous relaxation is occurring (on previously formed slip bands or at the grain boundaries), the resultant relief of local stresses may prevent high concentrations, thus preventing propagation of a deformation wave.

   a. Disappearance of stress-strain curve steps at higher temperatures (around 60°C for 2S aluminum, 120–150°C for Al-Cu alloys of 0.1–0.5 pct Cu) may be explained as a result of the increased creep rate in that range, since creep at constant stress becomes appreciable in roughly the same temperature ranges. The upper temperature limit for appearance of steps has been found to depend not only on temperature but on the amount

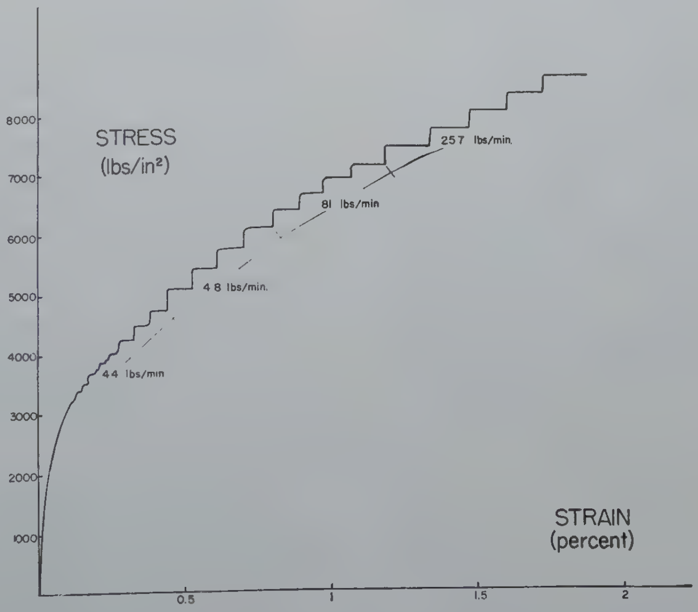

FIG 15—Effect of variation of load rate in 2S Aluminum.

Load applied continuously but with abrupt changes of rate as indicated.

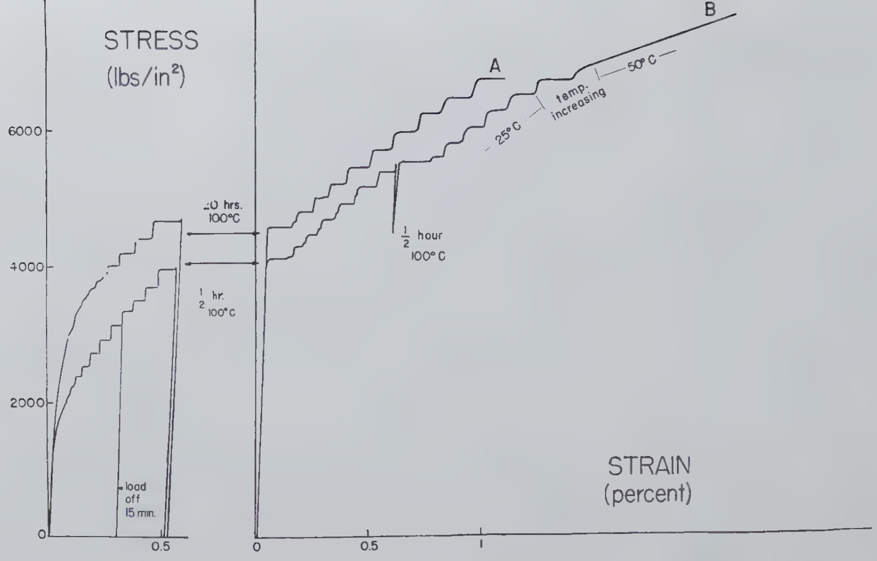

FIG 16—Effect of aging at elevated temperature—2S Aluminum.
(*A*) Entire tensile test conducted at 25°C but interrupted for 20 hr aging at 100°C. (*B*) All strain at 25°C except as indicated near end of curve.

and rate of previous plastic strain. That is, at higher temperatures, steps fade at smaller strains. (See Fig 14).

b. An alternate explanation of the high temperature disappearance of the step phenomenon would be that as solubility increases with temperature a point is reached where the solid solution is no longer supersaturated and therefore does not precipitate. On this basis, however, one would expect widely different upper temperature limits for 0.1 pct Cu and 0.5 pct Cu and also an appreciable effect of heat treatment such as 20 hr aging at 100°C. Since neither of these predictions is found true, it seems unlikely that solubility determines the temperature range for steps.

c. In all cases where loading was stopped and stress held constant for several minutes, further loading produced a period of elastic strain followed by a sharp and unusually large step of plastic deformation. The same effect was observed under conditions where no steps would otherwise occur (that is, in 99.99 pct pure aluminum or in Al-Cu alloys or 2S aluminum above or below the temperature range for step deformation). In the latter cases, however, step deformation did not persist but rapidly faded. These observations may be explained by the fact that holding stress constant for several minutes allows cessation of transient creep and thus makes possible enough stress concentration for strain to be propagated from grain to grain as a deformation wave.

d. It was frequently observed that, in a specimen being loaded at constant rate but at a temperature high enough to give a smooth stress-strain curve, a sudden decrease of temperature of only a few degrees produces a step in the curve. In this case also deformation soon reverts to a smooth stress-strain curve. As demonstrated by Carreker, Leschen, and Lubahn[24] recently, such a sudden drop in temperature in a stressed material creeping at constant rate momentarily stops all creep, but creep resumes after a short incubation time. Thus immediately after a decrease in temperature the rate of stress relief by creep is low enough to permit propagation of a plastic wave but resumption of creep prevents successive waves.

4. Only a small amount of relaxation in a grain just at the advancing deformation wave front is necessary to initiate plastic slip in adjacent grains ahead of it.

a. Waves have been observed to propagate with velocity varying over rather wide limits but with maximum around 80 cm per sec. This relatively slow velocity (as compared with the sound velocities for propagation of elastic waves) indicates that there is a slight delay in transmission of slip from grain to grain, and such a delay would be expected while relaxation on slip bands in one grain proceeds far enough to build up stress sufficient to initiate new bands in the adjacent grain (or to reactivate slip on old bands).

b. It would be expected that where continuous creep is occurring simultaneously with step deformation, a greater amount of relaxation would be necessary to initiate plastic strain in the next grain and consequently the rate of propagation would be slower. Comparison of different samples indicates that the less sharp the steps (that is, the more continuous creep) the lower the propagation velocity.

c. It is found in Al-Cu alloys that deformation at one point of a specimen (or more accurately in a region under a 3-mm long gauge) continues after the wave front has travelled 5–10 cm beyond. The strain occurring as the wave front passes is only a small part of the total, and further strain at the point continues at a decreasing rate.

Although the above four postulates represent a fairly consistent outline of the mechanism of transmission of the plastic deformation waves, some observed properties which are not completely explained by the postulates should be discussed. In general, their explanation requires more detailed knowledge of the mechanism, and of the dynamics of slip bands. Some aspects of the latter subject are to be discussed by C. Zener in the October 1948 ASM symposium on plastic deformation.

1. The steps are not of random size but occur at uniformly increasing stress intervals, approximately proportional to the total stress, and result in uniformly increasing amounts of strain. Further, both beginning and termination of the steps are in many cases sharp. A complete theory of the phenomena must therefore include both an explanation for the uniformity of stress increments between steps and a mechanism by which the deformation in single grains, once started, is terminated sharply at a definite strain value. A balance between these two factors then determines average slope of the stress-strain curve.

2. The exact mechanism by which the alloying elements effect hardening of the lattice to prevent plastic flow is not definitely known. Although it probably results from precipitation of aggregates of copper on the slip planes, it is difficult to picture a precipitation effect which occurs within the 0.1 second duration of the strain in such a way that precipitation hardening terminates the strain at a fixed value. It seems more plausible that each step results in complete relaxation across some slip planes, further strain being prevented by constraints of surrounding regions. Precipitation hardening on that plane then has time to occur before arrival of another deformation wave results in yielding elsewhere, again bringing stress across the same plane.

Summary

1. Plastic deformation of 2S aluminum and Al-Cu alloys is found to proceed according to a stair-step stress strain curve rather than at a continuous strain rate. The same effect is observed in 70/30 alpha brass.

2. The discontinuities are found to result from propagation of waves of plastic deformation along all or part of the specimen length; between occurrence of such waves practically no plastic strain occurs. Under varying conditions waves may be either very sharp or extended and velocities range from a few millimeters to around 100 cm per sec. Duration of the corresponding strain steps may vary from 0.1 sec to around 1 min.

3. The effect is found to depend on presence of an alloying element such as Cu or Mg in aluminum, and does not occur in 99.99 pct aluminum.

4. Dependence of the phenomenon on such parameters as temperature, amount and rate of strain, and heat treatment or aging has been studied, with results as summarized in the section on discussion. Of particular significance is the fact that the effect does not occur except in a limited temperature range (−10 to 60°C for 2S).

5. The type of deformation observed takes place by appearance of slip bands, but differs from the more usual type in that slip on individual bands is not independent; strain, once initiated, spreads to adjacent grains.

6. It is pointed out that yield point elongation, serrated stress-strain curves and Lüders' or Hartmann lines are examples of a similar propagation of plastic waves. Furthermore, all of these effects have in common that they appear to depend on precipitation hardening.

7. The proposed mechanism for the observed phenomenon of repeated plastic waves may be summarized as follows: Motion on slip bands during strain results in lattice vacancies and imperfections which greatly accelerate general diffusion and precipitation of copper aggregates in the immediate vicinity. Consequent precipitation hardening stops all relaxation on the bands. When stress eventually increases enough to initiate further slip at some point, the hardened condition of the lattice causes high stress concentrations in the vicinity, which facilitate spread of the strain into adjacent grains. As successive grains break down under the stress concentrations, a wave of strain spreads through the metal and is followed by further precipitation hardening, thus starting a new cycle.

Acknowledgments

The author wishes to acknowledge indebtedness to many of the staff of the Institute for the Study of Metals, particularly Professor C. Zener for stimulating discussions, Mr. David Houghton for carrying out many of the measurements, and Mr. John Gault for technical assistance; and also to Mr. Petersen and Mr. Tahl of the General Motors Electromotive Division for equipment and cooperation in making oscillograph measurements.

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On the Structure of Gold-silver-copper Alloys

JOHN G. McMULLIN[*] and JOHN T. NORTON[*]

Introduction

THE ternary system of gold-silver-copper is characterized by a solid solubility gap and a two phase region in which copper-poor and silver-poor phases coexist. At about 30 pct gold, the two phases become mutually soluble at temperatures below the melting temperature. As the gold content is increased, the solubility temperature of the alloys decreases until at about 80 pct gold, the two phases are soluble down to the lowest temperature at which the alloys will recrystallize.

Although the general form of the two phase region is known, its boundaries do not seem to have been investigated extensively. In an X ray diffraction study, Masing and Kloiber[1] have outlined the boundaries of this two phase field at 400 and 750°C. Using only microscopic techniques, Pickus and Pickus[2] determined a vertical section of the ternary diagram showing the 14 kt alloys (58.3 pct gold). These two reports are not in complete agreement.

It has been shown[3] that some of the ternary alloys are susceptible to age hardening and that the hardening is caused by the separation of a homogeneous alloy into two phases at the aging temperature. While the gold-copper binary system is an outstanding example of super lattice formation, Hultgren[4] has shown that a few per cent of silver added to gold-copper destroys the tendency for ordering. Because of the age hardening possibilities of these alloys, it seemed advisable to investigate the boundaries of the two phase field more in detail using an X ray diffraction method, so as to permit a better understanding of the aging phenomena and enable predictions as to the behavior of other alloys to be made. This is especially true for the 18 kt alloys (75.0 pct Au) at the lower temperatures since they are known to exhibit age hardening.

Experimental Procedure

Twelve ternary alloys were prepared having the compositions shown in Table 1 and graphically in Fig 1. The gold used was fine gold bars supplied by Handy and Harmon. The silver was a bar of high purity silver from the U. S. Bureau of Standards. The copper was a bar of vacuum-treated, high conductivity copper from the National Research Corporation.

Table 1 . . . Composition of Alloys

Alloy No.	Composition by Weight Per Cent			Solution Temperature °C	Lattice Constant of Solid Solution Angstrom Units
	Gold	Copper	Silver		
1	58.33	3.00	38.67	350	4.054
2	58.33	5.00	36.67	475	4.037
3	58.33	10.00	31.67	570	3.999
4	58.33	20.83	20.84	640	3.918
5	58.33	30.00	11.67	590	3.859
6	58.33	36.67	5.00	390	3.810
7	58.33	38.67	3.00	350	3.807
8	75.00	20.00	5.00		3.914
9	75.00	12.50	12.50	380	3.966
10	75.00	5.00	20.00		4.033
11	65.00	17.50	17.50	550	3.938
12	70.00	15.00	15.00	475	3.954

The pure metals in the form of powder were weighed out in proper proportions and melted in graphite in a high frequency induction vacuum furnace. They were heated to 1100°C and slowly cooled. The ingots were then removed from the crucible, inverted, returned to the crucible and remelted. This remelting procedure was intended to reduce segregation in the ingots. After remelting, the ingots were checked for weight loss. The weight loss in each ten gram ingot was held to less than 25 mg. The remelted ingots were cold rolled and then given a homogenizing heat treatment of 16 hr at 760°C to remove any remaining segregation.

Powder specimens were prepared by cutting the ingots with a fine file, one half the required amount of powder being taken from each end of the ingots. When the X ray diffraction pattern showed any difference in lattice constant between the ends of the ingot, the ingot was remelted and given an additional homogenization treatment.

All powder samples were sealed in evacuated pyrex tubes for heat treatment. Ordinary pyrex proved satisfactory for temperatures up to 650°C but above that temperature it was necessary to use a special high temperature pyrex glass. Annealing at temperatures below 500°C was done in a salt bath whereas for temperatures of 500°C and above an electric muffle furnace was used. In both furnaces the temperature control was ±5°C. In all annealing treatments samples of cold worked powder were placed in a furnace which was already at temperature. In this manner the specimens recrystallized directly to the equilibrium structure for that temperature. Time at temperature was selected so as to allow complete recrystallization, but very little grain growth. Specimens were quenched from the annealing temperatures by breaking the pyrex tubes in cold water.

X ray diffraction photograms were made of all the heat treated powders using copper radiation and a Phragmen

San Francisco Meeting, February 1949.

TP 2486 E. Discussion of this paper (2 copies) may be sent to *Transactions* AIME before April 15, 1949. Manuscript received July 1, 1948.

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[*] Instructor, Department of Metallurgy and Professor of Metallurgy, respectively, Massachusetts Institute of Technology.

[1] References are at the end of the paper.

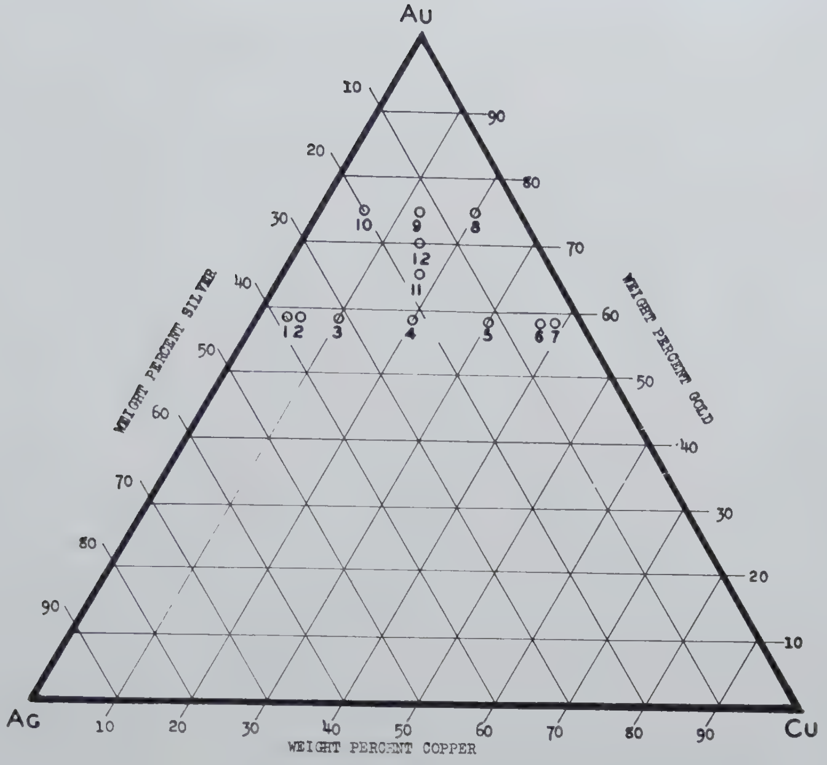

FIG 1—Compositions of the twelve alloys investigated.

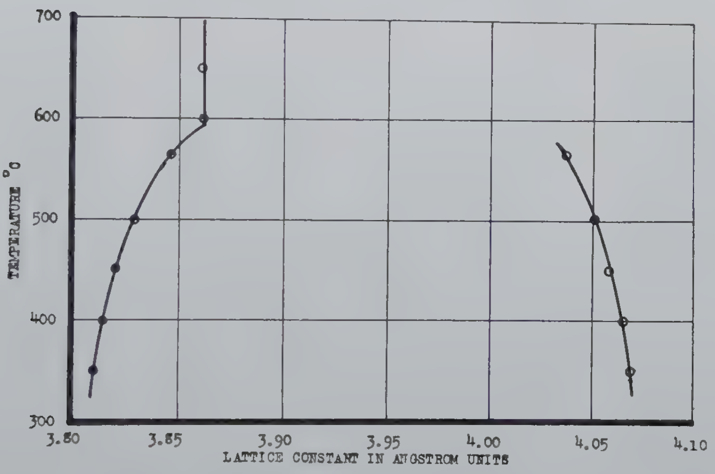

FIG 2—Lattice constants of alloy No. 5 quenched from the annealing temperatures indicated.

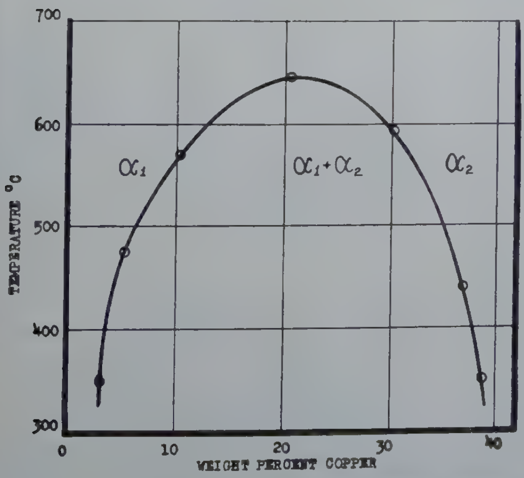

FIG 3—Vertical section through the ternary diagram showing the 14 karat alloys (58.3 pct Au).

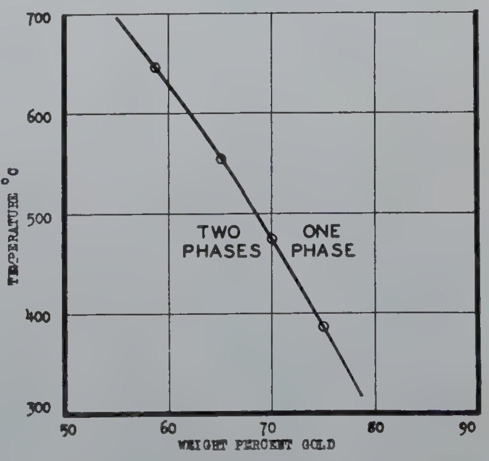

FIG 4—Vertical section through the ternary diagram showing alloys containing equal amounts by weight of silver and copper.

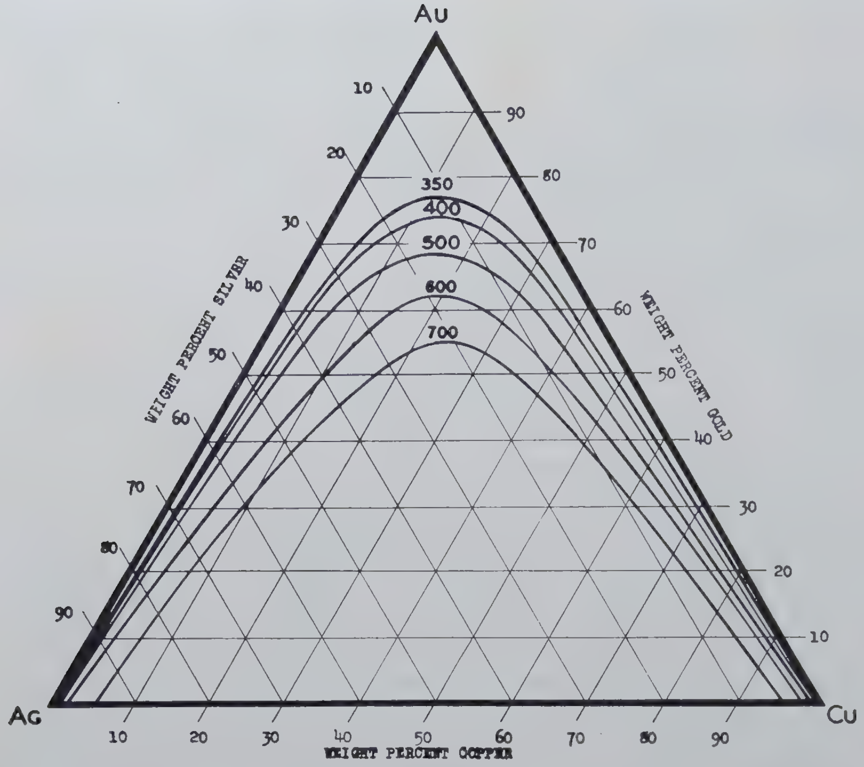

FIG 5—Isothermal sections defining the two-phased region in the gold-silver-copper ternary system.

focusing X ray camera. All the structures observed were face-centered cubic with no indication of ordering or tetragonality. The lattice constants of the phases were determined to ±0.002 Å based on a copper K alpha one wavelength of 1.54050 Å. In alloys where the pattern of the solute phase was weak this accuracy was not maintained. Also alloy No. 9 did not recrystallize completely when annealed below its solution temperature and its lattice constants were not accurately determined. Since each alloy was annealed at several temperatures above its solution temperature the lattice constants of the solid solutions listed on Table 1 are the average of several determinations and are probably accurate to ±0.001 Å.

Determination of Phase Boundaries

In order to determine the limits of the two phase field, the twelve alloys listed in Table 1 and plotted in Fig 1 were employed. Cold worked powder specimens of each alloy were annealed at several temperatures and quenched to room temperature. The lattice constants of each specimen were determined by X ray diffraction methods. For each alloy a plot was made of the lattice constant vs. annealing temperature. Fig 2 is typical of the twelve plots made in this manner. This plot shows the lattice constant of the gold-copper rich matrix phase as well as the larger lattice of the gold-silver rich solute phase. The diffraction pattern of the solute phase is very faint in some alloys, especially at temperatures just under the solution temperature. In alloys No. 1 and 7 the solute phase is present in such a small amount that it gives no visible diffraction pattern. In all alloys the variation in the lattice constant of the solvent phase is so large that the solution temperature can easily be determined. In Fig 2 the lattice constant of the alloy is constant for all temperatures above the solution temperature and decreases as the gold-silver rich phase is precipitated at temperatures below the solution temperature. The exact solution temperature is determined graphically by drawing a vertical line through the points above the solution temperature and the best smooth curve through the points below the solution temperature. The intersection of the vertical line and the curved line determines the solution temperature for the alloy in question. The solution temperatures of ten of the twelve alloys were determined in this manner. The solution temperatures of alloys No. 8 and 10 were below the lowest temperature at which these alloys would recrystallize.

Alloys No. 1, 2, 3, 4, 5, 6 and 7 all lie on one vertical section through the ternary system while alloys No. 9, 12, 11 and 4 lie on another perpendicular to it. These two sections are shown on Fig 3 and 4 where the solution temperatures of the alloys are plotted against their compositions. Using these two vertical sections and the silver-copper binary diagram, it was possible to sketch in the limits of the two phase region at several temperatures in the ternary system as shown in Fig 5.

Results

Fig 5 shows horizontal sections of the ternary diagram outlining the two phase field at five different temperatures. Each section is drawn from three points in the ternary field and two points taken from the binary copper-silver diagram. It is estimated that the error in the position of these boundaries is of the order of ±2 pct in composition. Fig 4 shows a vertical section for equal parts of copper and silver in the range from 50 to 100 pct of gold.

The horizontal section at 400°C is in good agreement with the results obtained by Masing and Kloiber.[1] The vertical section corresponding to the 14 kt alloys is only in fair accord with the results of Pickus and Pickus[2] but these investigators presented their results only as approximations.

The horizontal section at 350°C extends into the region of the 18 kt alloys and thus shows how these alloys are susceptible to age hardening by transformation from a single homogeneous phase into two separate phases of different composition.

Acknowledgments

The authors wish to express their indebtedness to Messrs. Leach and Christie of Handy and Harmon for providing the pure gold used in the present investigation, and to Mr. Albert Mahfuz for performing much of the experimental work.

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Stress and Strain States in Elliptical Bulges

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Introduction

A GREAT number of the investigations on the plastic flow of metals have been concerned with the establishment of a "universal" stress-strain relation. In such a relation some stress function when plotted against a strain function should yield identical curves for the various stress states.

In the first investigation of this type, Ludwik and Scheu[1] plotted the maximum shearing stress as a function of the maximum principal strain. Later Ros and Eichinger[2] introduced two universal stress-strain relations, the one relating the maximum shearing stress to the maximum shearing strain, and the other relating a stress invariant, suggested by von Mises and Haigh, to the corresponding strain invariant. (In more recent investigations the stress and strain invariants are frequently supplemented with some factor to render their meaning more lucid.) A further suggestion which has not attracted appreciable attention is that by Baranski[3] who used stress and strain deviators.

The most common means of experimentation to determine the relation between stress and strain consists in subjecting thin walled tubes to combined internal pressure and axial tension.[4a,4b,4c] This method allows the study of plastic flow under stresses which are variable in two directions. However, the plastic flow which can be obtained in this manner is comparatively small, being limited by either tension failure or instability.

For copper,[4a] only the relation between maximum shearing stress and maximum shearing strain yielded good agreement. On the other hand, tests on a steel[4b] and on an aluminum alloy[4c] resulted in systematic deviations if any of the discussed universal stress-strain relations were used. It would seem, therefore, that the agreement mentioned above for copper is only incidental and explained by its high rate of strain hardening compared to that of other metals.

Much larger strains than experienced in the tube tests can be obtained by subjecting a thin membrane of a ductile metal, which is restrained at its periphery, to a uniform hydraulic pressure. The thin sheet forms a deep bulge before it fails. The stresses and strains in such a bulge increase with increasing distance from the edge of the clamping "die," the maximum stresses and strains occurring at the pole (crown) of the bulge. While the stress and strain states are determined by the contour of the bulge, the absolute magnitude of the stresses and strains depends upon the hydraulic pressure. The bulge contour is in turn correlated with the geometry of the die opening.

The deformation and fracture characteristics of circular bulges, that is, bulges formed with circular clamping dies, have been the subject of numerous experimental and analytical investigations.[5,6,7] It has been shown that plastically deformed circular bulges develop large and comparatively uniform strains before failure by instability[6b,6c,6d] and closely assume a spherical shape.[6d] Also the distribution of strains across the contour of the bulge is dependent on the metal being investigated and is correlated with, but cannot be predicted from, the metal's stress-strain characteristics.

On the other hand, oblong or elliptical bulges, that is, bulges formed with elliptical clamping dies, are not as susceptible to analytical analysis and have not been investigated to the extent that circular bulges have. The few available data[6a,7c] indicate that stress states are obtained at the poles of the bulges, varying between plane strain and balanced biaxial tension, depending upon the geometry of the die opening.

In this paper, the strain state and curvatures exhibited by three bulge shapes, a circular and two elliptical bulges, Fig 1, are analyzed experimentally using methods described in previous publications.[6a,6c] An attempt is made to derive the stress-strain relations for these bulges, which represent strain states in which the ratio of the two positive principal strains varied between 1.0 and 0.35. In addition, tension tests yielded data for a value of -0.5 for this strain ratio.

Such an analysis should indicate the applicability of the various laws correlating stress with strain to the stress and strain states occurring in bulged shapes.

Definitions and Nomenclature

The definitions of the major stress and strain quantities used in this paper are as follows:

s_1, s_2, s_3 = principal normal stresses
$s_1 > s_2 > s_3$
t = shear stress
e = conventional (unit) strain
$\epsilon = ln\,(1 + e)$
$\epsilon_1, \epsilon_2, \epsilon_3$ = principal natural strains
γ = shear strain

The maximum shear stress:

$$t_{max} = \frac{s_1 - s_3}{2}$$

Frequently, the flow stress, $s_1 - s_3 = 2t_{max}$, rather than the maximum shear stress is used.

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[1] References are at the end of the paper.

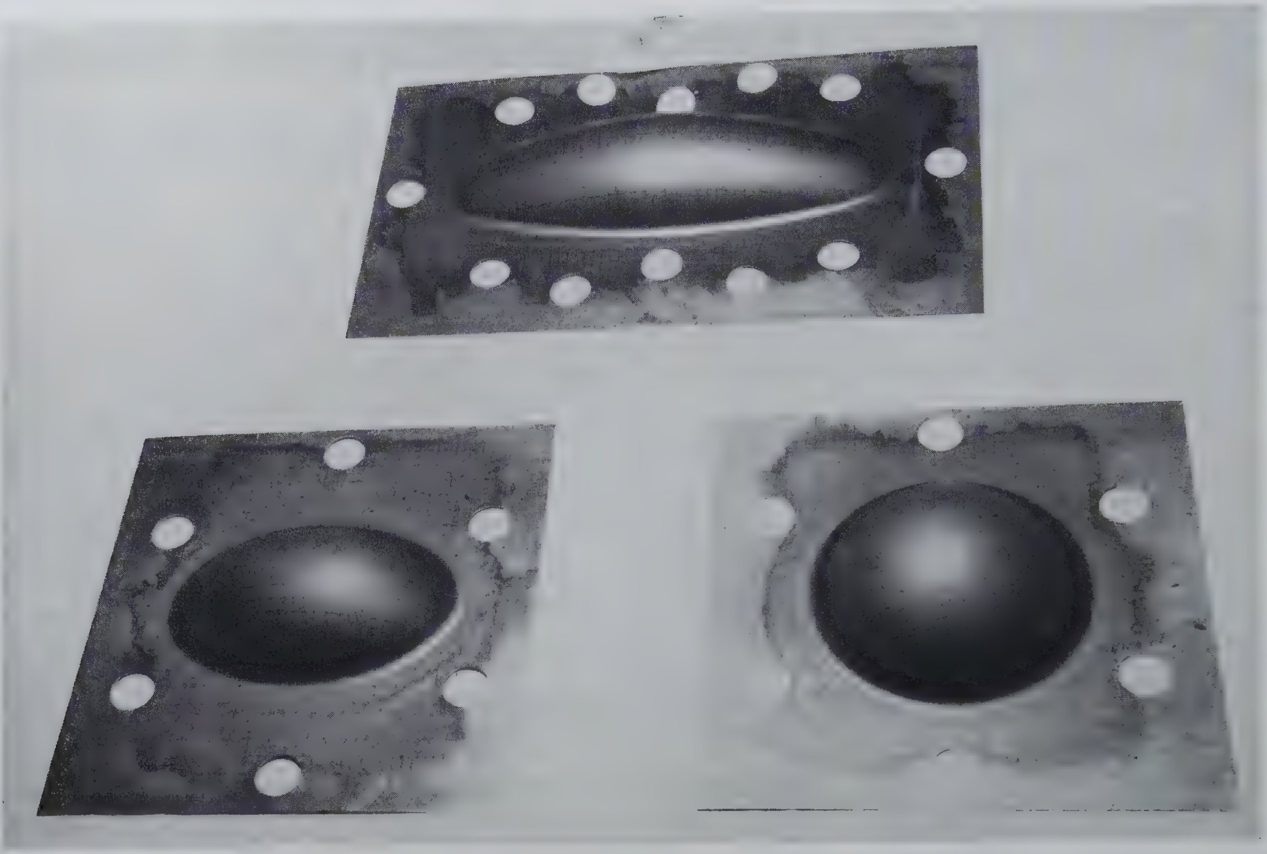

FIG 1—Typical shapes formed on hydraulic bulging of thin sheets.

The largest principal natural strain, ϵ_{max}, is the value of the principal strain having the largest absolute value.

The maximum shear strain:

$$\gamma_{max} = \gamma_2 = \epsilon_1 - \epsilon_3$$

The effective stress:

$$\bar{s} = \frac{1}{\sqrt{2}} \sqrt{(s_1 - s_2)^2 + (s_2 - s_3)^2 + (s_3 - s_1)^2}.$$

The octahedral shearing stress, $t_{oct} = \frac{\sqrt{2}}{3} \bar{s}$.

The effective strain:

$$\bar{\epsilon} = \frac{\sqrt{2}}{3} \sqrt{(\epsilon_1 - \epsilon_2)^2 + (\epsilon_2 - \epsilon_3)^2 + (\epsilon_3 - \epsilon_1)^2}$$

The octahedral shearing strain, $\gamma_{oct} = \sqrt{2}\, \bar{\epsilon}$.

The factors in the equations for the effective stress and effective strain serve to render $\bar{s} = s_1$ and $\bar{\epsilon} = \epsilon_1$ for uniaxial tension ($s_2 = s_3 = 0$ and $\epsilon_2 = \epsilon_3 = -\epsilon_1/2$).

Material and Procedure

Cartridge brass (70 pct copper, 30 pct zinc) sheet of 0.040 inch thickness was chosen for the experimental investigation. The rolling and annealing schedule for the sheet was designed to produce isotropic material. To further insure uniformity, the sheet was annealed at 850°F for one-half hour and then air cooled.

In order to determine the degree of isotropy in the sheet, tension tests (specimens ¾ in. in width with a 5-in. gauge length) were made parallel to, transverse to, and 45° to the rolling direction. The three stress-strain curves were found to be identical, Fig 2. In Fig 3, the natural strains, ϵ_2 and ϵ_3, from two series of tests are plotted as a function of ϵ_1. It is seen that the sheet conforms reasonably to isotropic conditions.

Before bulging, the blanks were photogrided[8] with a 20 line-to-the-inch net, the grid being parallel and perpendicular to the rolling direction of the sheet.

In all, six bulge shapes were made by using appropriate clamping dies. There were two circular bulges, two ellipses* with a ratio of minor to major axis of 0.60 and two ellipses* with this ratio 0.32. (See Fig 1.)

The equipment and procedure for testing bulges and measuring the pertinent quantities have been described in previous publications on circular bulges.[6c,6d] Each bulge was loaded in steps and unloaded after each step. The pressure was recorded and the principal strains and the height of the bulge surface at various distances from the pole determined.

The strains were measured along the two lines of the photogrid, which were initially located parallel to the short and long axis of the die. Over a considerable area in the center of the bulge, the strain values represent, with sufficient accuracy, the two principal strains in the bulge surface along its intersections with planes containing the pole and the major and minor axis of the die, respectively. Examples of the distribution of these strains are given in Fig 4 and 5. These graphs illustrate that the elliptical bulges exhibited a rather narrow region in the vicinity of the pole in which the strains were nearly constant. As to be expected, the strains decreased rapidly with increasing distance from the pole in the direction of the small axis, but only slowly in the direction of the large axis of the die.

The strain values at the pole obtained from the trend curves in Fig 4 and 5 are taken as the two principal strains, ϵ_1 (perpendicular to major axis) and ϵ_2 (perpendicular to the minor axis), for the respective load value.

Fig 6 and 7 illustrate distributions of the strain state, defined by the ratio of

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* These contours were not exactly true ellipses but were bulged using clamping dies whose openings were constructed by using arcs of circles. See Ref. 6e for die geometry.

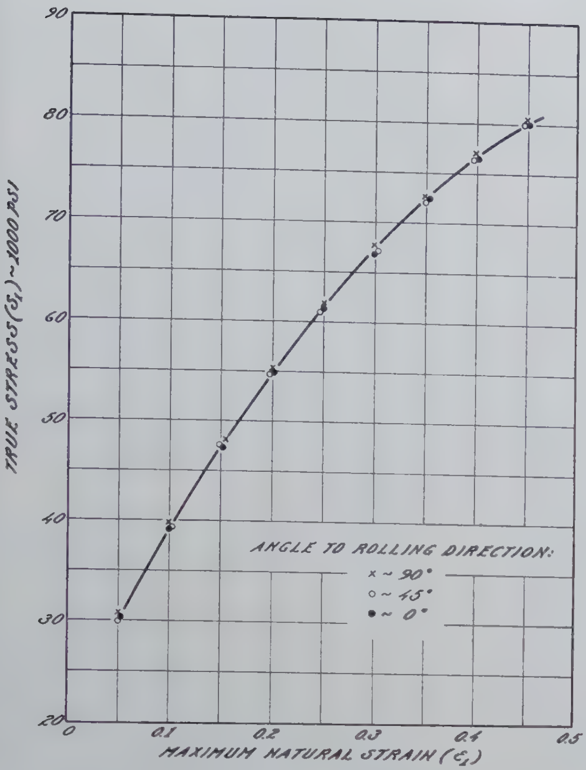

FIG 2—Stress-strain curve for annealed 70-30 brass in tension.

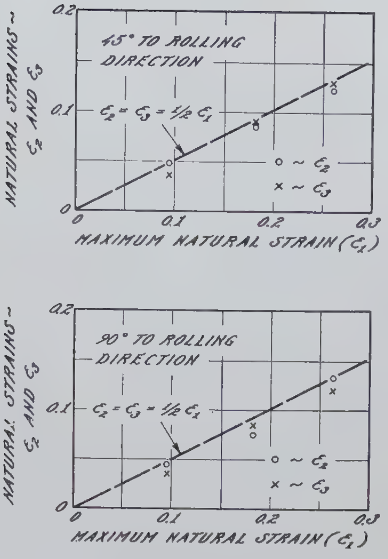

FIG 3—Natural strains ϵ_2 (width) and ϵ_3 (thickness) as a function of ϵ_1 (longitudinal) for tension tests on annealed 70-30 brass sheet (0.040 in. thick).

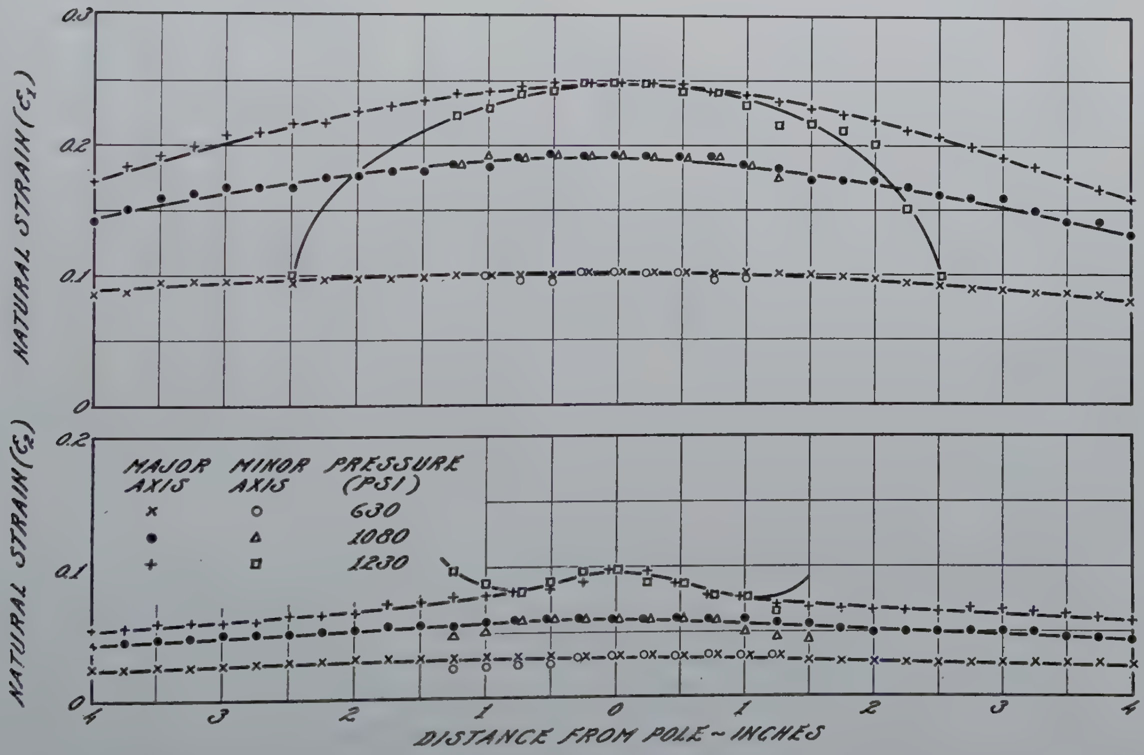

FIG 4—Distribution of strains (ϵ_1 and ϵ_2) at various pressures for annealed 70-30 brass bulged to elliptical contour (ratio of minor to major axis = 0.32).

the two principal strains in Fig 4 and 5. According to these graphs, the strain state differed only slightly over the crown of the bulge surface while large variations were noted in areas in the vicinity of the clamped edge.

The radii in the two principal directions of a bulge were determined from the height for various chord lengths, as described in a previous publication.[5d] An example of the results of this procedure, for a few selected load readings, is shown in Fig 8. The values of the radii extrapolated to zero chord length are considered to be the radii of curvature at the pole, R_1 and R_2 in the two principal directions.

Since the bulge shapes were not fractured (only the one bulge having a ratio of minor to major axis of 0.32 was taken to fracture) it was possible to section the bulges for tension tests. These tension specimens were cut from the center portion of the bulges along the minor axis so that the pole was included. The additional strain resulting from the tension test was measured by using a radial strain gauge. In all cases no appreciable load was carried by the specimen until the specimen had straightened.

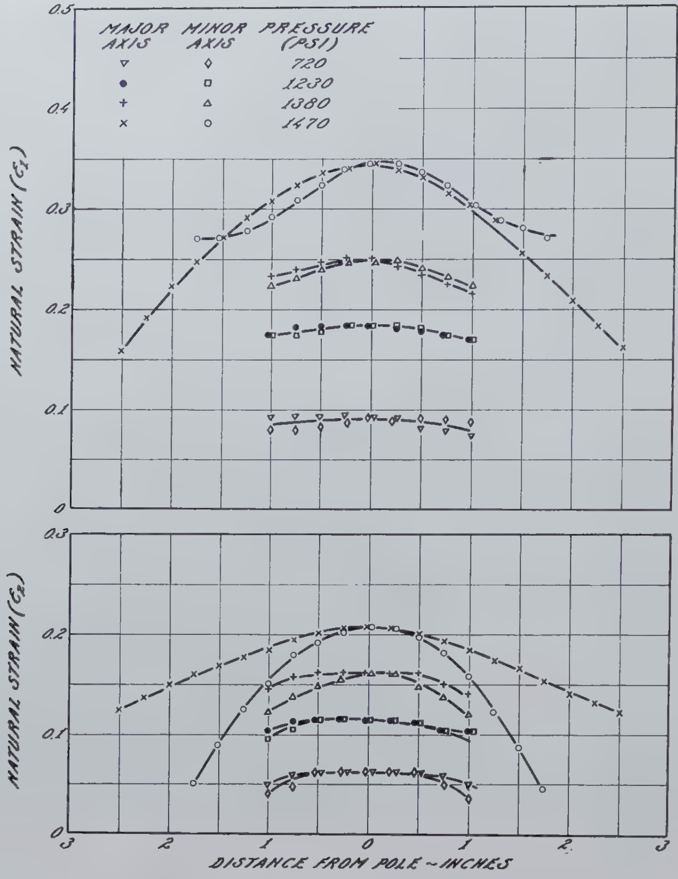

FIG 5—Distribution of strains (ϵ_1 and ϵ_2) at various pressures for annealed 70-30 brass bulged to an elliptical contour (ratio of minor to major axis = 0.60).

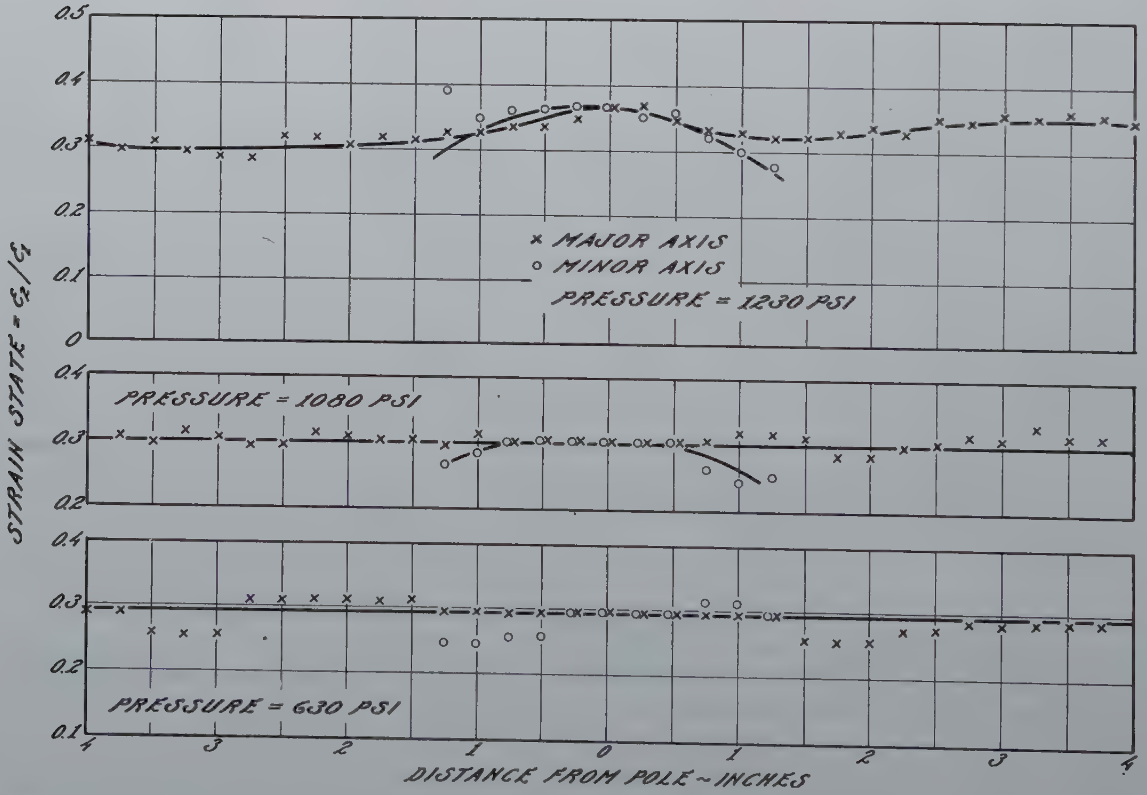

FIG 6—Distribution of strain state (ratio: ϵ_2/ϵ_1) in annealed 70-30 brass bulge (ratio of minor to major axis = 0.32). Derived from Fig 4.

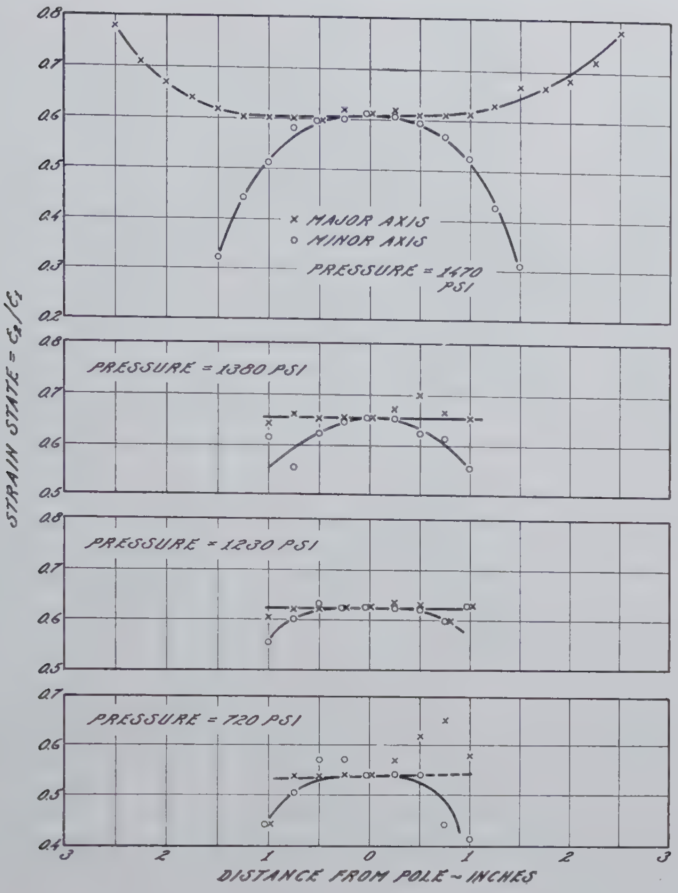

FIG 7—Distribution of strain state (ϵ_2/ϵ_1) in annealed 70-30 brass. Bulge (ratio of minor to major axis = 0.60). Derived from Fig 5.

Results

The bulging data are illustrated in Fig 9 to 12. The pressure, p, is plotted against each of the three principal strains ϵ_1, ϵ_2, and $-\epsilon_3$ in Fig 9 to 11, and the radii against the largest principal strain, $-\epsilon_3$, in Fig 12.

The values of ϵ_2 and ϵ_1 are replotted in Fig 13 as functions of $-\epsilon_3$. This graph reveals that during the forming of each bulge the strain state remains practically constant.

For the further analysis, average values of the various quantities obtained from the trendline through the experimental points for the two parallel tests are used. In general, for identical conditions two tests yielded results in close agreement.*

Analysis

The equilibrium of a shell element, Fig 14, yields the following relation:

$$\frac{p}{h} = \frac{s_1}{R_1} + \frac{s_2}{R_2} \text{ or } s_1 = \frac{R_1 p}{h} - \frac{R_1 s_2}{R_2} \qquad [1]$$

The experimental data yield the quantities p, h, R_1, and R_2. This leaves two unknowns for which only one equation is available. The other equation must be obtained from some established law of plasticity.

In this analysis the following assumptions will be made concerning conditions at the pole of the bulges:

1. Volume changes can be neglected during plastic flow, or:

$$\epsilon_1 + \epsilon_2 + \epsilon_3 = 0 \qquad [2]$$

2. Stress states encountered during bulging are practically biaxial, or:

$$s_3 \approx 0 \qquad [3]$$

3. Edge effects are negligible as are any bending or flexural stresses.

EFFECTIVE STRESS AND EFFECTIVE STRAIN

A relation, which is widely accepted, states that the second stress invariant is a function only of the second strain invariant and is independent of the stress state. Thus, for a given value of $\bar{\epsilon}$, the value of $\bar{s}$ is given by the curve for balanced biaxial tension, in Fig 15. The definition of $\bar{\epsilon}$, Eq 4, and the constant volume condition, Eq 2,

$$\bar{\epsilon} = \frac{\sqrt{2}}{3} \sqrt{(\epsilon_1 - \epsilon_2)^2 + (\epsilon_2 - \epsilon_3)^2 + (\epsilon_3 - \epsilon_1)^2} \qquad [4]$$

yield values of $\bar{\epsilon}$ for the various bulged shapes, corresponding values of ϵ_1 and

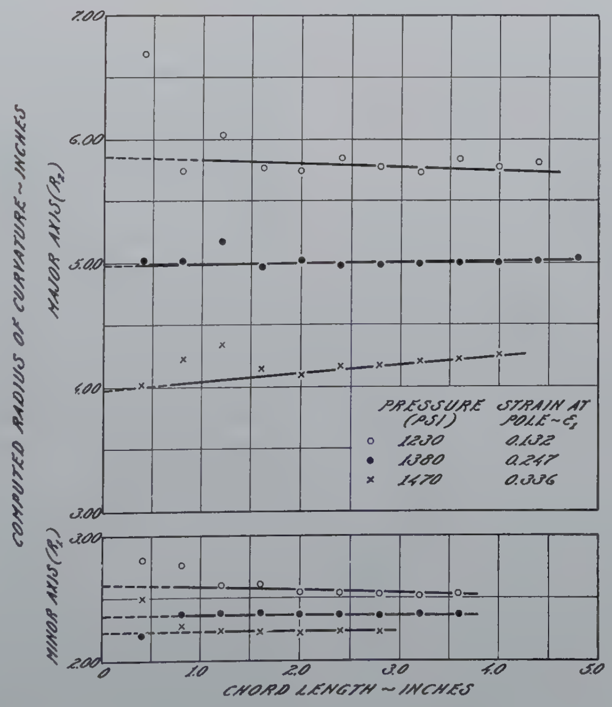

FIG 8—Example of determination of radii of curvature at pole for elliptical bulge (ratio of minor to major axis = 0.60).

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* In the case of the elliptical bulges having a ratio of minor to major axis of 0.32 some deviation in the values was noted. This probably was due to the considerable slippage during one of the tests. However, this difference was found to be of little influence on the results of the analysis.

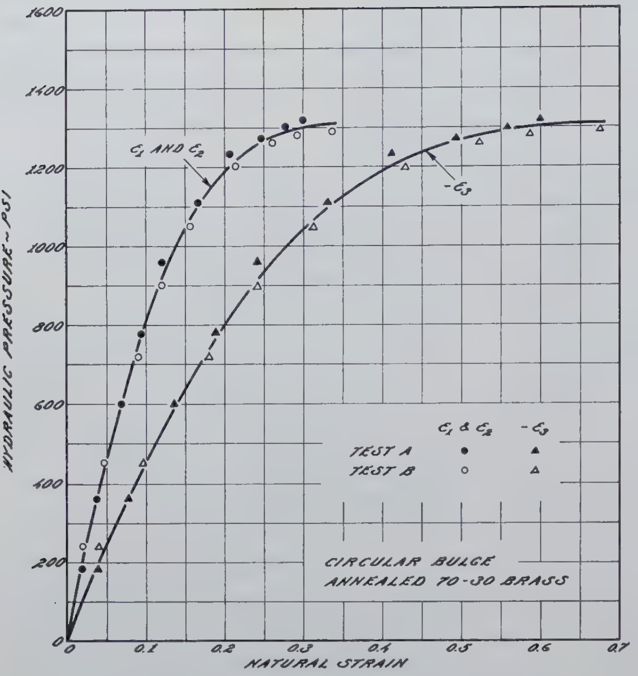

FIG 9—Hydraulic pressure as a function of the three principal natural strains at pole for circular bulging of annealed brass sheet.

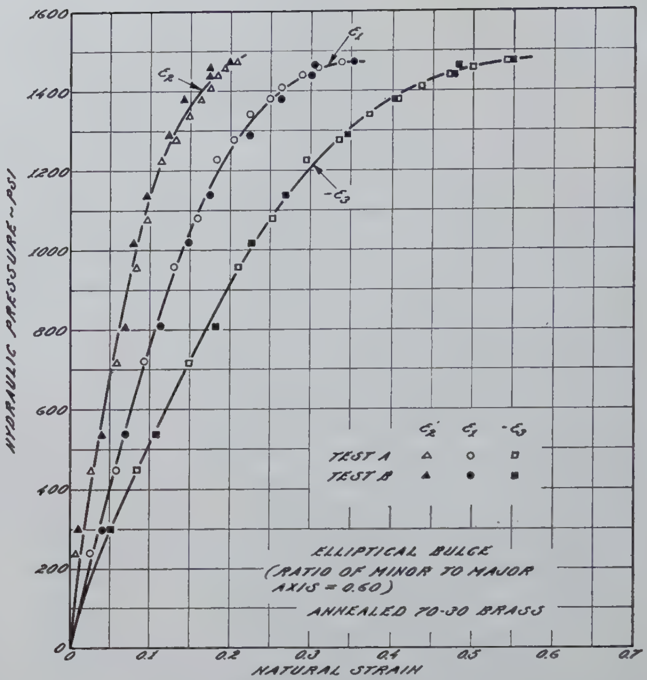

FIG 10—Hydraulic pressure as a function of the three principal natural strains at pole for elliptical bulging of annealed brass sheet.

ϵ_2 being determined experimentally. For these data Fig 9 to 12 then give the pressure, p, and the radii of curvature, R_1 and R_2, and the value of $\bar{s}$ which is defined as follows:

$$2\bar{s}^2 = (s_1 - s_2)^2 + (s_2 - s_3)^2 + (s_3 - s_1)^2 \quad [5]$$

Simplifying Eq 5 for bulges, where $s_3 \approx 0$:

$$\bar{s}^2 = s_1^2 - s_1 s_2 + s_2^2 \quad [5a]$$

Now by letting $c_1 = \bar{s}$, $c_2 = \frac{R_1 p}{h}$ and $c_3 = \frac{R_1}{R_2}$ and substituting Eq 1 in Eq 5a, a quadratic equation for s_2 is obtained:

$$s_2^2 - s_2\left[\frac{2c_2c_3 + c_2}{c_3^2 + c_3 + 1}\right] + \left[\frac{c_2^2 - c_1^2}{c_3^2 + c_3 + 1}\right] = 0 \quad [6]$$

from which:

$$s_2 = \frac{\frac{2c_2c_3 + c_2}{c_3^2 + c_3 + 1} \pm \sqrt{\left[\frac{2c_2c_3 + c_2}{c_3^2 + c_3 + 1}\right]^2 - 4\left[\frac{c_2^2 - c_1^2}{c_3^2 + c_3 + 1}\right]}}{2} \quad [6a]$$

The corresponding value of s_1 may be obtained by substituting the value of s_2 in Eq 1.

The above calculations were carried out for the two elliptical bulges. However, the value of the ratio of s_2/s_1 were found to be approximately 0.55 in the case of the ellipse with a ratio of minor to major axis of 0.60 and 0.40 in the case of the ellipse with a ratio of 0.32. These values of the ratio s_2/s_1 are not consistent with the experimentally determined strain state. Apparently the effective stress-effective strain relation is not sensitive to small changes in stress states.

ST. VENANT'S RELATION

An alternative method to determine the stresses present in elliptical bulges, from Eq 5, is to use as the second equation some relation between the known strains ϵ_1, ϵ_2, $\epsilon_3 = \epsilon_1 - \epsilon_2$ and the stresses s_1, s_2, $s_3 \approx 0$. Such a relation has been suggested by St. Venant. Previous investigations have shown that St. Venant's relation can be used to determine accurately the strains resulting from a varying stress state, such as occurs in deep drawing.[9] Because of the consistent strain state, ϵ_2/ϵ_1 = constant, found to exist in bulges according to Fig 13, St. Venant's relation also applies to finite strains, rather than to strain rates, as follows*:

$$\frac{s_1 - s_2}{s_2 - s_3} = \frac{\epsilon_1 - \epsilon_2}{\epsilon_2 - \epsilon_3} \quad [7]$$

yielding for bulging, $s_3 = 0$:

$$\frac{s_2}{s_1} = \frac{\epsilon_2 - \epsilon_3}{\epsilon_1 - \epsilon_3} \quad [8]$$

For the two elliptical bulges investigated, where $\epsilon_2/\epsilon_1 = 0.60$ and 0.36, respectively (Fig 13), this yields $s_2/s_1 = 0.85$ and 0.70, respectively. Introducing these values into Eq 1 then permits calculating s_1 for these two bulges from the known quantities represented in Fig 9 to 12, according to the following respective relations:

$$s_1 = \frac{p}{h}\left(\frac{R_1R_2}{R_2 + 0.85R_1}\right) \quad (9a)$$

and

$$s_1 = \frac{p}{h}\left(\frac{R_1R_2}{R_2 + 0.70R_1}\right) \quad (9b)$$

The results of these calculations are shown in Fig 15, s_1 being plotted against the largest principal strain, $-\epsilon_3$. In Fig 16, $s_1 = s_1 - s_3 = 2t_{\max}$ and $\bar{s}$ are replotted as a function of the maximum shearing strain, $\gamma_{\max} = \gamma_2 = \epsilon_1 - \epsilon_3$, and Fig 17 illustrates the relation between s_1 and $\bar{s}$ and $\bar{\epsilon}$ for the bulges investigated. The corresponding curves for the circular bulges (and also for uniaxial tension) are added to Fig 15 to 17.

The final results of the bulging tests on brass, represented in Fig 15 to 17, agree closely to those of the tests on

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* The validity of St. Venant's relation has been investigated repeatedly.[4,9,10] It can be derived from this data that in the range of strain states occurring in bulging, namely, $\epsilon_1 > \epsilon_2 > 0$, the stress ratio s_2/s_1 may be actually as much as 5 pct larger than that given by St. Venant's relation. However, a correction of this magnitude would change the stress, s_1, calculated from Eq 8 by not more than one to two percent. A correction of this magnitude does not affect the conclusions derived from the present investigation.

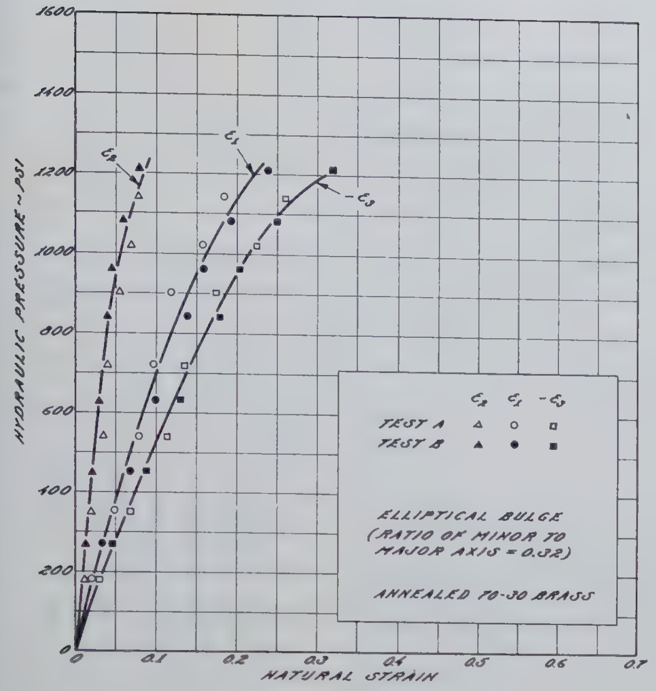

FIG 11—Hydraulic pressure as a function of the three principal natural strains at pole for elliptical bulging of annealed brass sheet.

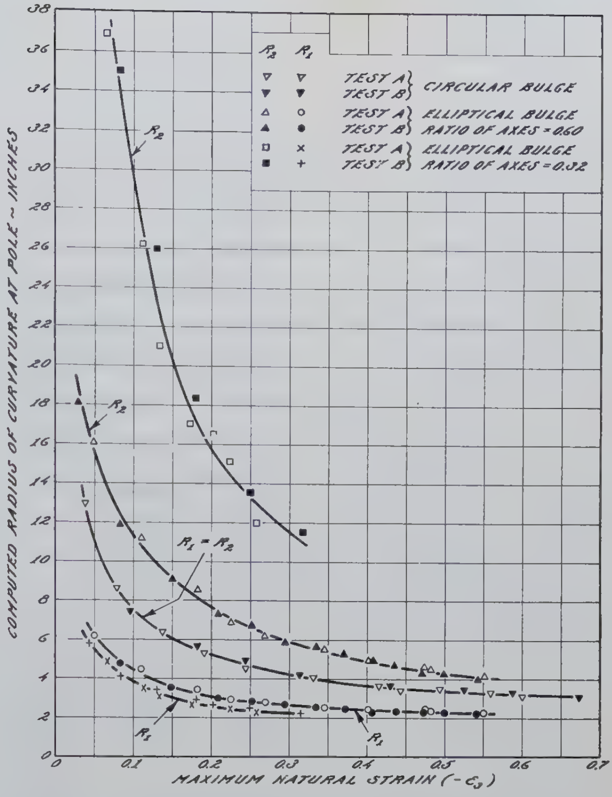

FIG 12—Radii of curvature (R_1 and R_2) as a function of the maximum strain at the pole for the three bulge shapes.

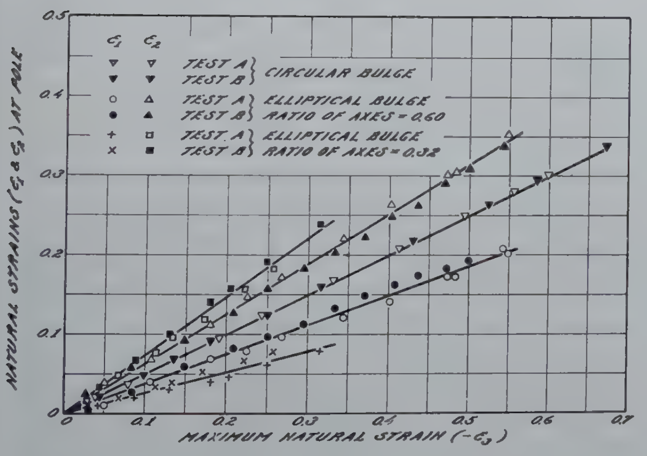

FIG 13—Principal strains (ϵ_1 and ϵ_2) as a function of the maximum principal strain (ϵ_3) for the various bulges made in annealed 70-30 brass.

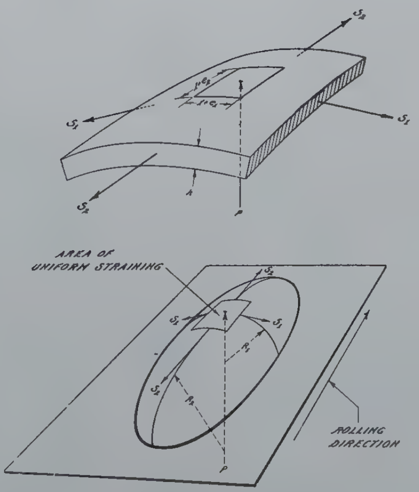

FIG 14—Stress, strain, and geometrical conditions in an elliptical bulge.

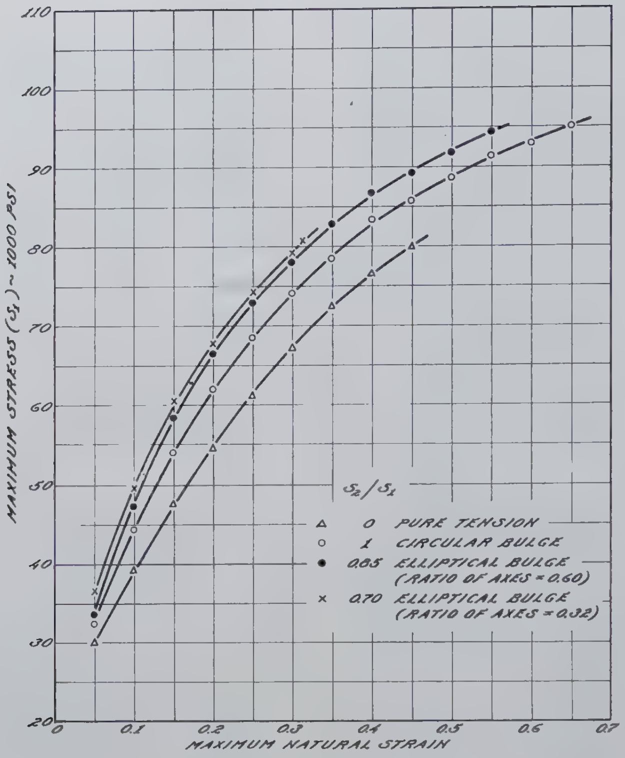

FIG 15—Maximum stress (s_1) as a function of the maximum natural strain ($-\epsilon_3$ at pole for bulges and ϵ_1 for tension test) for annealed 70-30 brass tested under various stress states.

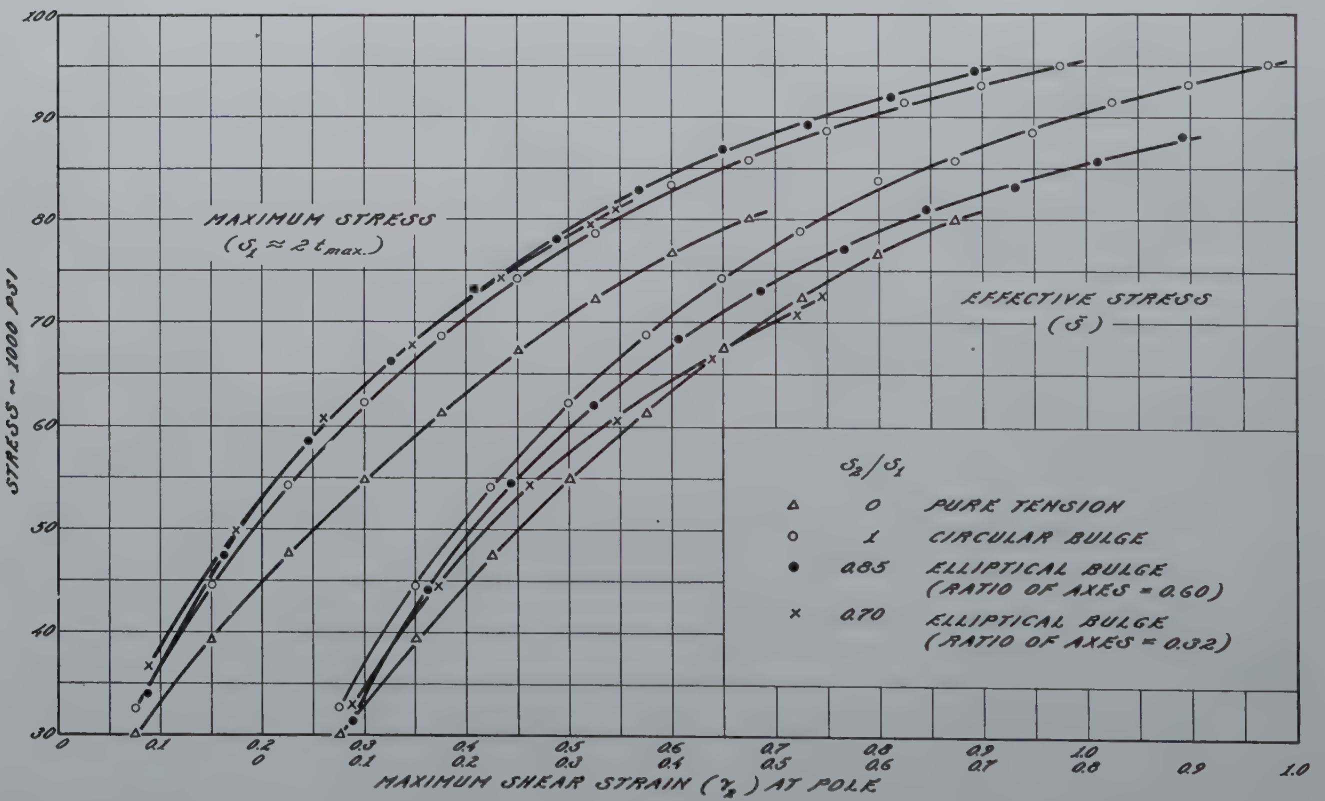

FIG 16—Maximum stress (s_1) and effective stress ($\bar{s}$) as a function of maximum shear strain (γ_2) for bulge series and tension test on annealed 70-30 brass (values for bulges at pole).

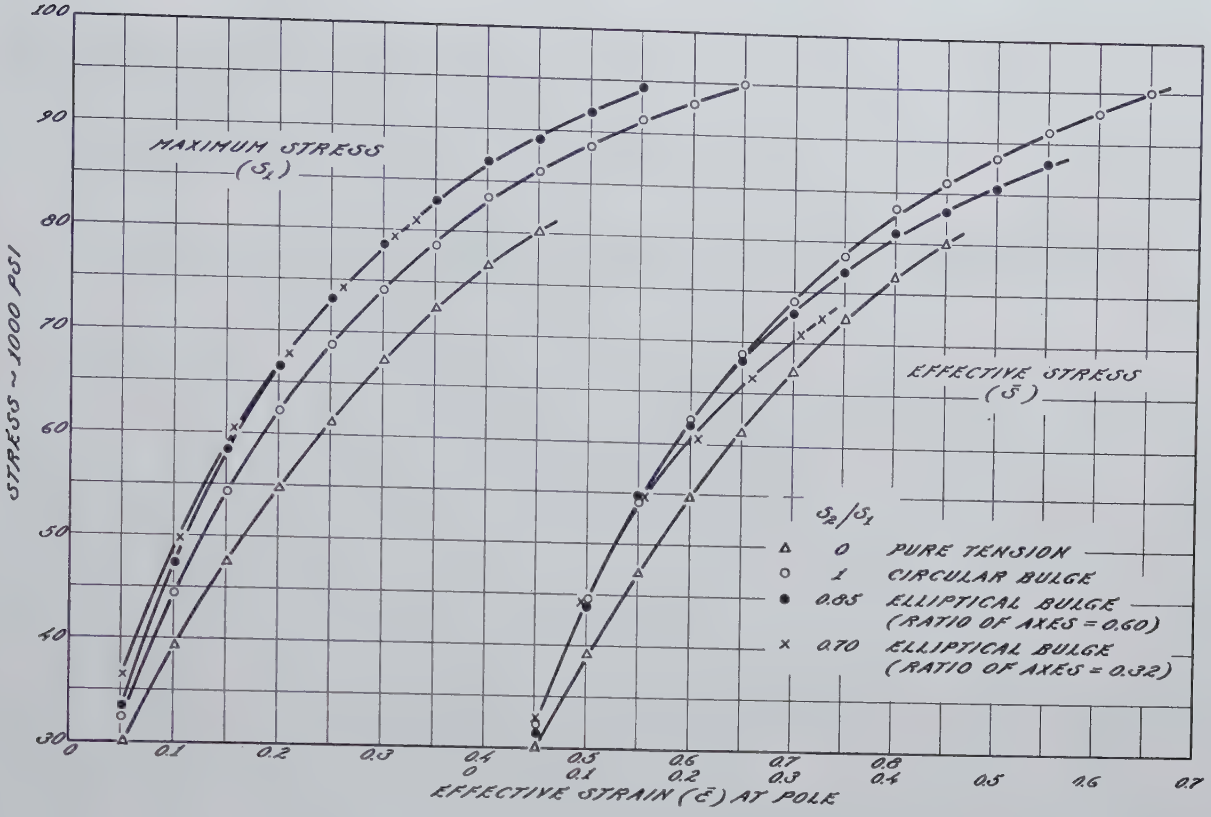

FIG 17—Maximum stress (s_1) and effective stress (s) as a function of effective strain ($\bar{\epsilon}$) for bulge series and tension test on annealed 70-30 brass (values for bulges at pole).

copper tubes. Of the various types of stress-strain curves, only the relation between the largest principal stress (or more generally between the maximum shearing stress) and the maximum shearing strain yields identical curves for the three bulges investigated, within the limits of experimental accuracy. As discussed in the introduction, this agreement is not universal but appears to apply only to metals with a high rate of strain hardening. The simplest representation of the largest principal stress as a function of the (absolutely) largest principal strain yields, for stress states approaching plane strain, stress values as much as 10 percent higher than for balanced biaxial tension. On the contrary, the effective stress-effective strain ($\bar{s} - \bar{\epsilon}$) relation yields for conditions near plane strain, lower values of the stress invariant than for balanced biaxial tension.

Thus, none of the universal stress-strain relations proposed to date applies accurately, in the range of biaxial tension.

UNIAXIAL AND BIAXIAL TENSION

In order to establish any law of plasticity, some simple stress state must be selected as a basis. In the present investigation, two such stress states were investigated, uniaxial tension, $s_2 = s_3 = 0$ and balanced biaxial tension, $s_2 = s_1$, $s_3 \approx 0$* (present in circular bulging).

While any of the recognized theories of plasticity requires identical stress-strain curves for these two stress states, the present tests yielded according to Fig. 15 to 17 considerably higher stresses for balanced biaxial tension than for uniaxial tension.

As mentioned in the procedure the various bulges were sectioned and the strips tested in tension. The results of these tests are shown in Fig 18. The flow stress shown by these specimens closely approximated values expected if the metal had been prestrained in tension. It would seem, therefore, that some effect or effects other than anisotropy or stress state, must be operating to cause higher stress values in bulging. One of these effects might well be the nonuniformity of strain values over the bulge contour induced by the lateral restriction of the sheet. In other terms, non-homogeneity of strain in a structure results in higher values for plastic flow than would be called for by the common laws of plasticity. If this effect is sufficient to cause the noted difference between bulging and tension, it would be expected that the amount of this discrepancy would vary with the degree of nonuniformity of the strain.

The main objective of the present tests was to compare the stress-strain relations for bulges of various shapes. Therefore, for the aforegoing analysis the stress-strain curve for balanced biaxial tension, where s_1 is given as a function of $-\epsilon_3$, was used as a basis. Between the various investigated bulges the degree of lateral restriction should be approximately the same and since the metal can be considered identical, the observed differences in the stress-

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* In these tests the pressure did not exceed 1500 psi while s_1 was then almost 100,000 psi. Therefore, s_3 did not exceed one percent of s_1.

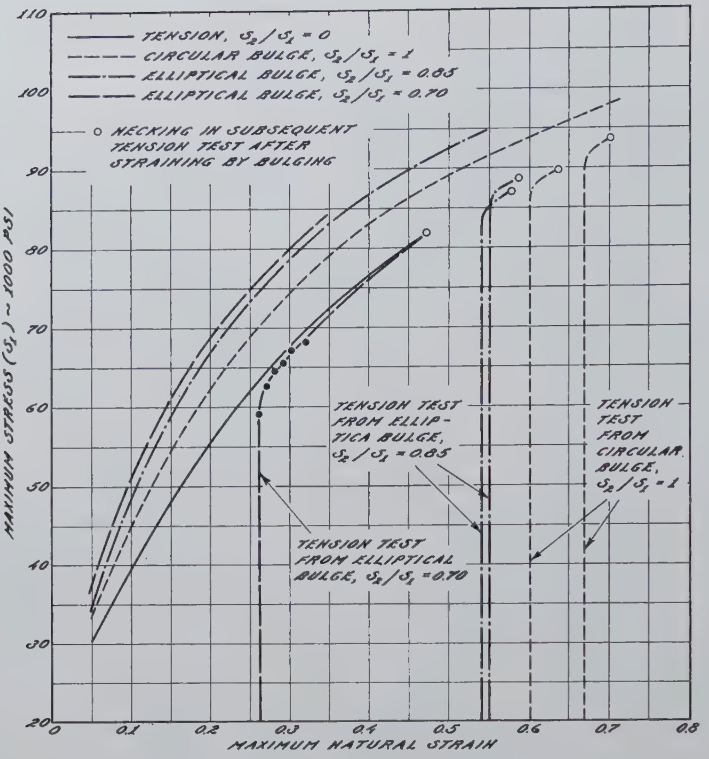

FIG 18—Results of tension tests on pieces sectioned from the various bulges. (The maximum strain in bulging is $-\epsilon_3$, while in tension ϵ_1 is used).

strain curves must be a result of the applied laws of plasticity.

Conclusions

Summarizing the results of this investigation, the following conclusions may be drawn regarding stress and strain states in elliptical bulging:

1. Stress values in elliptical bulges may be analyzed by using St. Venant's law of plasticity and the equation for equilibrium of a shell.
2. Stress states varying between balanced biaxial tension and close to plane strain can be obtained by bulging thin sheet using the proper die geometry.
3. None of the universal stress-strain relations proposed to date applies accurately in the range of biaxial tension.
4. The discrepancy between bulging and tension values of the stress required for plastic flow may be due to the nonhomogeneity of strain across the contour of the bulge.

Acknowledgments

The authors are indebted to Mr. W. F. Brown, Jr. and Mr. F. C. Thompson for their help in formulating the program and to Mr. M. F. Jones for his aid in the experimentation.

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A Study of Textures and Earing Behavior of Cold-rolled (87–89 pct) and Annealed Copper Strips

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A CONSIDERABLE amount of work has been reported in the literature in regard to the texture and earing behavior of copper strip. The rolling texture of copper has been confirmed as $(110)[\bar{1}12]$ and $(112)[11\bar{1}]$, which yields ears of a drawn cup at the position 45° from the rolling direction.[1–3] The recrystallization texture has been established as the cubic or (100) [001] texture, where the earing positions are at 0° and 90° to the rolling direction.[4–8] It has also been reported that in the development of cubically aligned grains of copper strips, the percentage of this cubic texture increased with an increase of final reduction and final annealing temperature.[8,9] A comprehensive study on H.C. copper (British commercial copper of high-conductivity quality = Cu 99.95 pct, O_2 0.03 pct, Ag 0.003 pct, Fe 0.005 pct and Pb < 0.001 pct) was made by Cook and Richards.[6] They concluded that the recrystallization textures could be described as one or more of the following textures: (1) a single texture (100) [001], (2) a twin texture $(110)[\bar{1}12]$ and (3) a random orientation, depending upon the previous history of the specimen concerned.

The effect of various alloying additions in copper was reported by Dahl and Pawlek.[10] They found that certain alloying additions, such as 5 pct Zn, 1 pct Sn, 4 pct Al, 0.5 pct Be, 0.5 pct Cd, or 0.05 pct P suppressed the formation of cubic texture. Brick, Martin and Angier[11] reported that the cold rolled textures due to various additions fitted a rather simple pattern. However, the recrystallization textures were subject to very considerable variations. In the discussion of this paper, Baldwin stated that deoxidized copper containing 0.02 pct P gave a complicated recrystallization texture at lower temperature. When this copper was annealed at high temperature, a single texture appeared which was described as $(110)[\bar{1}11]$ but, according to a private communication from Baldwin, this orientation reported was in error and should have been reported as $(110)[\bar{1}12]$. He also reported that the earing positions of drawn cups were at 60° to the rolling direction.[12]

Recently, Howald, in his discussion on the paper by Hibbard and Yen,[13] reported that the rolling texture of phosphorus deoxidized copper, containing from 0.006 to 0.020 pct phosphorus, was of the pure copper type. When these coppers were annealed at lower temperatures, they exhibited a random orientation, and when they were annealed at higher temperatures they had a mixed $(111)[1\bar{1}0]$ and (100)[001] texture, depending on the severity of the final reduction and annealing temperature.

However, the specific influence of phosphorus and other impurities on the recrystallization textures and the deep drawing properties of copper strip has not been thoroughly reported. Therefore, an attempt has been made in the present work to determine the rolling and recrystallization textures and also the earing behavior of five types of commercial copper and thereby to evaluate the effect of phosphorus and some other significant impurities on the development of texture for cold reductions of about 87 to 89 pct.

Materials Used

The five types of copper employed in the present investigation were two phosphorus deoxidized coppers of different phosphorus content (0.007 and 0.013 pct P), an oxygen-free copper (OFHC), an electrolytic tough-pitch copper, and a fire-refined tough-pitch copper. These materials were subjected to a thorough spectroscopic and chemical analysis. The designations and the chemical compositions were as shown in Table 1.

The coppers, FA1, FA2 and FA3, were hot-forged from 3-in. billets into a ½ × 6-in. plate and cold rolled to the ready-to-finish gauge indicated below. FA4 and FA5 were hot rolled and scalped to ready-to-finish gauge. The grain size of all the materials in the ready-to-finish condition was about 0.030 to 0.045 mm. Table 2 shows the last stage of the production schedule for each copper strip used.

Experimental Procedure

ANNEALING, GRAIN SIZE AND HARDNESS DETERMINATIONS

Specimens of each type of copper were finally annealed in air for periods of one hour at temperatures ranging from 300 to 1600°F and were subsequently cooled in air. The average grain diameter of the annealed specimen was estimated by comparing with a standard grain size chart. Hardness was determined on the Rockwell 15 T scale.

CUPPING TESTS

Cups were made in a blanking and drawing set, in which blanks of 2-in. diam were drawn to a cup of 1.25-in. diam with an average depth of about 0.75 in. The clearance between the punch and die was about 0.032 in. The ears of the cup were measured with a special fixture which read the height of ears to one-thousandth of an inch on every ten-degree interval along the circumference of the cup.

POLE FIGURES

The usual transmission diffraction method with unfiltered copper radiation was employed to determine the pole-figures of the specimens cold-rolled or annealed at 900°F. All the pole-figures were derived from the positions of intensity maxima on 111 diffraction rings of the X ray photograms taken at 10° rotation of a

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San Francisco Meeting, February 1949.

TP 2506 E. Discussion of this paper (2 copies) may be sent to *Transactions* AIME before April 25, 1949. Manuscript received September 14, 1948.

* Chase Brass and Copper Co., Waterbury, Conn.

[1] References are at the end of the paper.

Table 1 . . . The Designation and Chemical Compositions of Copper Strips Used

Designation	Chemical Composition (pct)									
	Cu	Pb	Fe	Ni	Sn	Si	Zn	P	O_2	Misc.
FA1 (Phosphorized)	99.97	<0.0005	0.0015	0.001	0.0002	<0.001	<0.005	0.013	Not detected	
FA2 (Phosphorized)	99.97	<0.0005	0.0015	0.001	<0.0001	<0.001	<0.005	0.007	Not detected	
FA3 (Oxygen-free)	99.98	<0.0005	0.001	0.001	<0.0001	<0.001	<0.005	<0.0003	Not detected	
FA4 (Electrolytic)	99.95	0.0007	0.0015	0.001	0.0002	<0.001	<0.005	<0.0001	0.013	Te + Se
FA5 (Fire Refined)	99.92	0.002	0.0017	0.022	0.002	<0.001	<0.005	<0.0001	0.025	0.029

Table 2 . . . The Production Schedule of Copper Strips Used

Specimen	Ready to Finish Condition		Final Condition	
	Gauge (In.)	Anneal (°F)	Gauge (In.)	Reduction (pct)
FA1	0.291	900	0.032	89.0
FA2	0.287	900	0.033	88.5
FA3	0.269	900	0.033	88.6
FA4	0.291	As Hot-rolled	0.033	88.7
FA5	0.253	As Hot-rolled	0.032	87.0

specimen about its rolling and transverse directions. For specimens annealed at the higher temperatures, a structure integrating camera constructed by Wilson and Brick[14] was used. The camera was designed to cover a specimen area of about 1.5 × 3 cm. The specimens were etched with 50 pct HNO_3 to a thickness of about 0.004 in.

GLANCING PHOTOGRAMS

Photograms obtained with a glancing X ray beam were used to detect the presence of cubically aligned grains and to evaluate the change in recrystallization textures. The X ray beam was directed at an angle θ to the rolling plane and in the transverse plane, where θ is Bragg's angle for the radiation used. By applying Bragg's law, $n\lambda = 2d \sin \theta$, the wavelength of Cu-K α radiation, λ is 1.537 Å, the interplanar distance of the (100) plane of copper, d, is 3.608 Å and for the second order of reflection, $n = 2$, the Bragg angle for 200 diffraction will be about 25°.

Fig 1*a* and *b* shows the ideal orientations superimposed upon the outline of (111) and (100) pole figure of cold-rolled copper.[3,15] The shaded arc at the vertical position represents the portion of 111 and 200 Debye-Scherrer rings produced in the glancing photograms. It will be seen that both 111 and 200 rings pass nearly through the center of the projection. Therefore, any grains with (111) or (100) planes present in the rolling plane will reflect to the center of the arc of the 111 or 200 diffraction rings, respectively. In addition, these 111 and 200 rings also cross the first order intensity regions of the deformation texture so that any grains in the deformation texture would most probably be detected.

The specimens were etched with 50 pct HNO_3 to a thickness of about 0.015 in., so that any defects or inhomogeneities on the surface could be eliminated. The specimen was then mounted on the goniometer with the rolling direction normal to the X ray beam and the rolling plane inclined at an angle of 25° to the beam. The optimum exposure time was found to be a total of 10 min. with a potential difference of 35 PKV and a current of 10 ma. Similar photograms were also taken by using the structure integrating camera on the samples annealed at 1400 and 1600°F, where the grain size was found to be too large for the setup used for the lower temperature specimens.

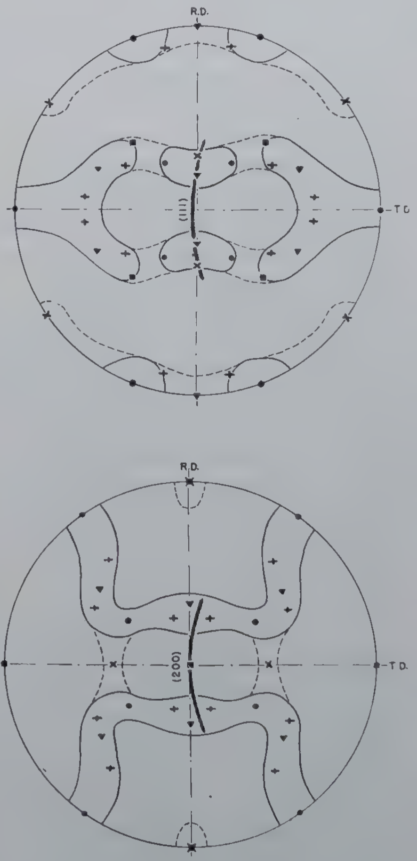

FIG 1—Ideal orientations superimposed upon the outline of the (111) and (100) pole-figures of cold-rolled copper.

The shaded arc at vertical position represents the portion of 111 and 200 Debye-Scherrer Rings produced in glancing photograms. Orientations indicated as follows: ● $(110)[\bar{1}12]$, ▼ $(112)[11\bar{1}]$ + $(124)[53\bar{3}]$, ■ (100)[001], × (110)[001]. *a*. (above). *b*. (below)

Discussion of Results

Fig 2 shows the Rockwell hardness and the average grain size of the five types of copper strips as annealed one hour at various final annealing temperatures. The presence of phosphorus appears to contribute to the grain growth at higher temperatures. The higher softening temperature of specimen FA1, which contained 0.013 pct P, is also quite evident. These results are in good agreement with the work reported by Webster, Christie and Pratt on drawn wires.[16] For the fire-refined copper, FA5, grain growth was suppressed to some extent and a slight effect on the softening temperature was noticed.

The results of the cupping tests and the glancing photograms of each specimen as cold-rolled or annealed at various temperatures are shown in Fig 3 and 4. Specimen FA1 showed no change of earing position at lower temperatures, while at higher temperatures the ears shifted from 45° to an angle of 40° from the rolling direction. Specimens FA3, FA4 and FA5 showed a typical behavior of copper, in that the ears occurred at the 0°–90° position and the earing height increased with the increase in annealing temperature. The earing position of specimen FA2 was somewhat complicated. It appeared that there were two transition zones, at 450° and 1400°F, where the earing position changed from 45° to 0–90° and returned to the 45° position when annealed at 1600°F. Referring to the glancing photogram, Fig 4, some correlation between the earing position and the grain orientation is noticeable. In the series of glancing photograms of

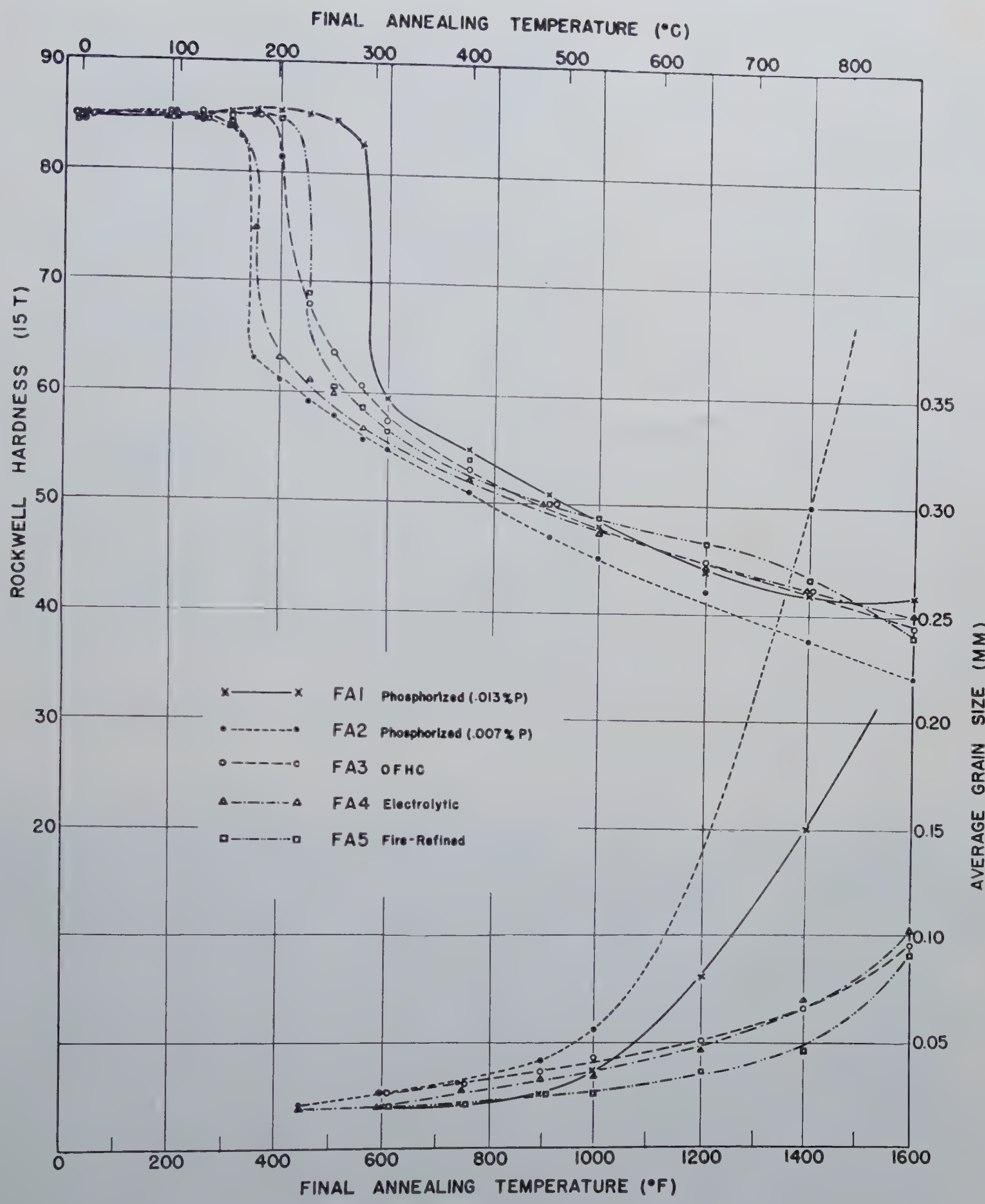

FIG 2—The effect of final annealing temperatures on hardness and grain size of five different types of copper strips.

FA1, the grain exhibited a rather random pattern at 600°F, at which temperature the height of ears was a minimum. A small amount of cubically aligned grains was observed, however. As the preferredness gradually developed the cubically aligned grains diminished and a corresponding increase in the height of the ears was noticed. In specimens FA3, FA4 and FA5 the concentration of cubically aligned grains was found to be considerable even at lower temperatures, while the degree of preferredness of cubic texture increased with increasing annealing temperature. Similar results were also observed in specimen FA2, annealed at lower temperature.

However, for specimens annealed at 1400 and 1600°F some uncertainties were aroused due to the larger grain size with accompanying lack of definition of these Debye-Scherrer rings. Thus, two series of photograms were taken by the integrating camera as shown in Fig 5. It was noted that, for specimen FA2 annealed at 1400°F, the pattern showed that the grains possessed certain definite preferred orientations in spite of the fact that practically no ears were observed in the drawn cups. This leads to the assumption that the effect of the presence of the cubic texture which yielded ears at 0° and 90° and that of the other textures yielding ears at 45° were just balanced, so that the resultant effect on ears was neutralized. This assumption was also proposed by Howald[17] in regard to 95-5 Cu-Zn alloy. He found that this alloy with 20 pct cubic texture and 80 pct of (113)$[\overline{2}\overline{1}1]$ plus

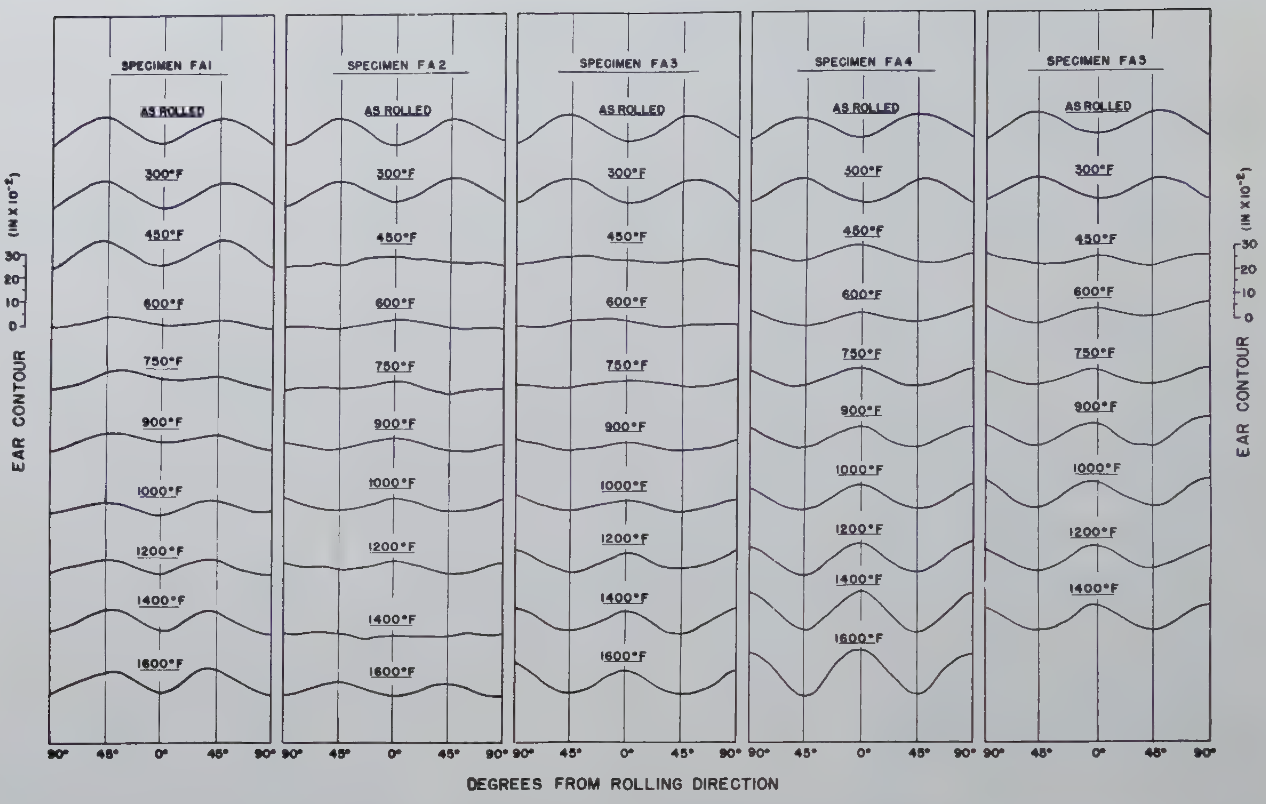

FIG 3—Ear contour on cups drawn from five types of copper strips annealed one hour at the temperatures indicated.

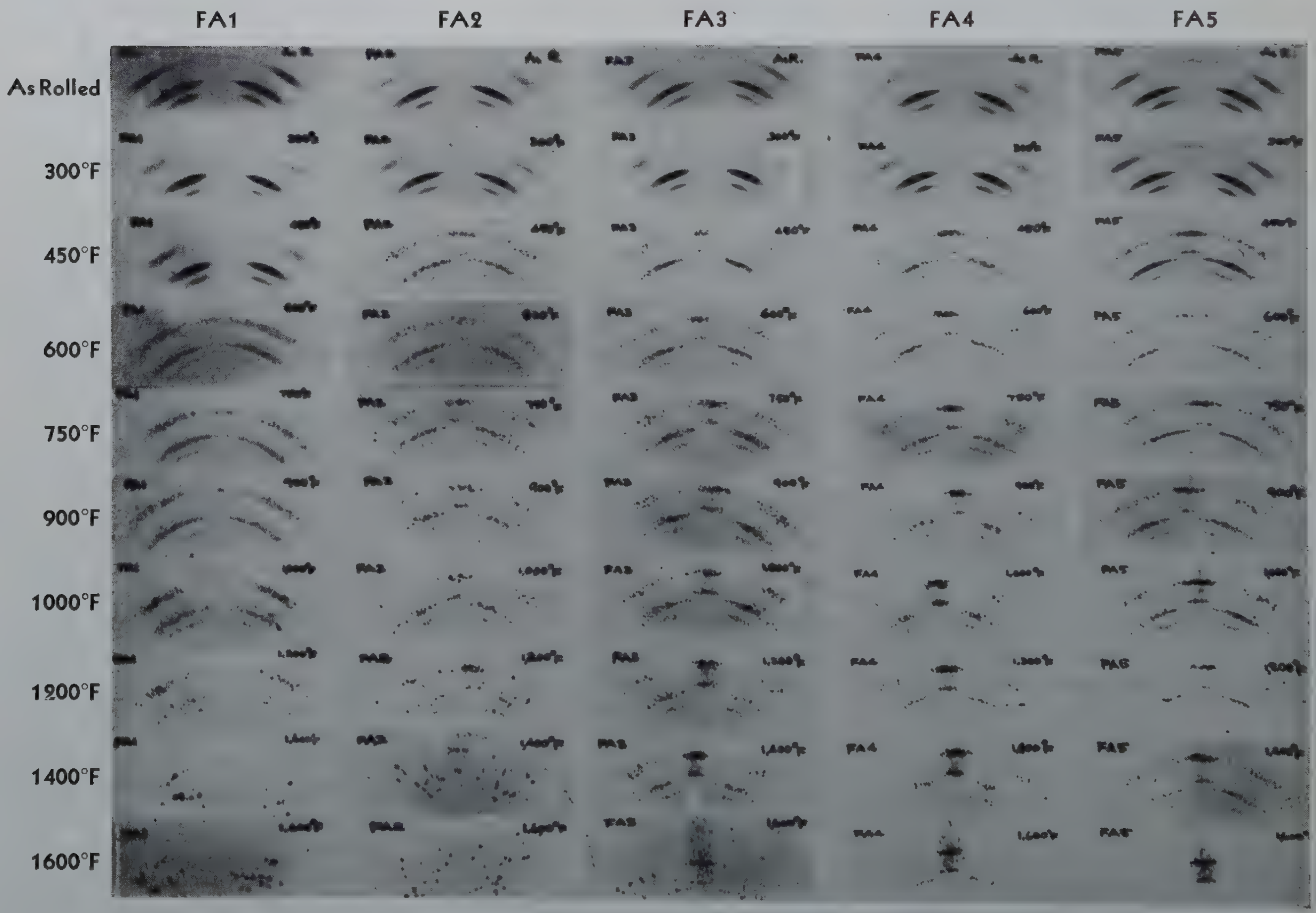

FIG 4—Glancing photograms for five types of copper strips annealed one hour at the temperature indicated. Photograms reduced to one-half the original size.

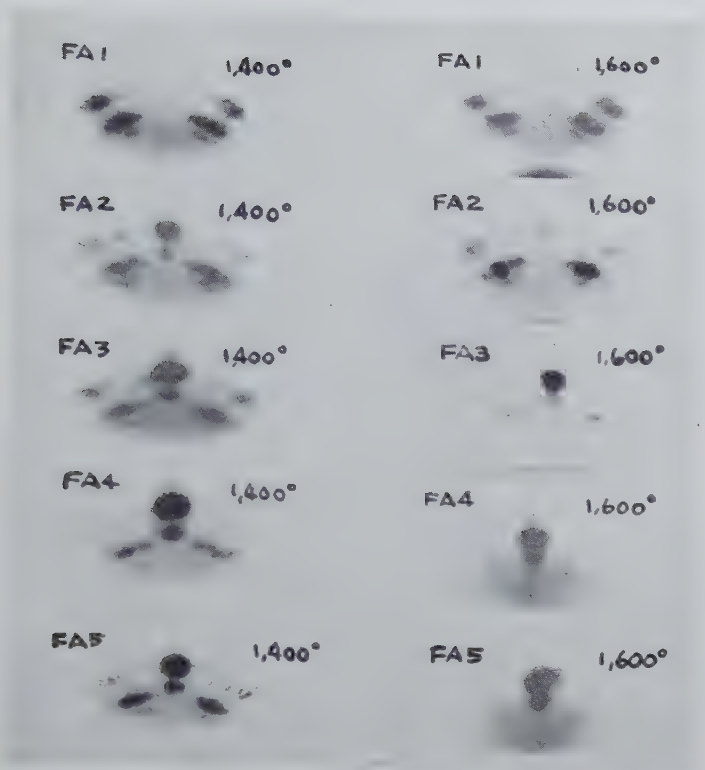

FIG 5—Glancing photograms taken by structure integrating camera for specimens annealed one hour at 1400 and 1600°F.

$(11\bar{5})[321]$ produced a cup of no ears. Furthermore, for the same specimen annealed at 1600°F, the decrease in the amount of cubic texture resulted in a change in the position of the ears to 45° from the rolling direction.

The pole figures of specimens in the cold-rolled condition were substantially the same as reported by previous investigators.[3,7,11] The major orientations can be described as $(110)[\bar{1}12]$ + $(112)[11\bar{1}]$. Fig 6 *a*, *b* and *c* shows the rolling texture of specimens FA1, FA3 and FA5. Greater spread of the distribution of (111) planes on the pole-figure of specimen FA1 was noticeable.

Pole figures of all specimens annealed at 900°F were made (Fig 7). No appreciable difference was found between specimens FA2, FA3, FA4 and FA5. The annealing textures were composed of a strong (001)[100] texture superimposed on the retained rolling textures with a mixture of minor orientations $(124)[53\bar{3}]$, $(110)[\bar{1}12]$ and $(112)[11\bar{1}]$. These orientations have been reported as the three important ones in cold-rolled copper.[3] In phosphorus deoxidized copper (0.013 pct P), FA1, a somewhat random recrystallization texture was obtained which may be described as a texture composed of $(112)[11\bar{1}]$, $(110)[\bar{1}12]$ and (100)[001].

For specimens annealed at higher temperatures, the pole figures were derived from photograms taken by the integrating camera. Fig 8*a* shows the texture of FA1 annealed at 1600°F which can best be described as $(112)[11\bar{1}]$ + (110)[100]. However, no texture of the type $(111)[\bar{1}10]$ or cubic orientation[13] is noticeable. Referring to the photograms of specimen FA1 at 1400 and 1600°F in Fig 5, the absence of (100) or (111) pole in the rolling plane is quite evident. For specimen FA2, annealed at the same temperature, a mixture of textures $(113)[\bar{2}\bar{1}1]$, $(110)[\bar{1}12]$, and (100)[001], was found. The pole figure of specimen FA3 annealed at 1600°F was similar to that obtained at the lower temperature, except that the intensity of the residual deformation texture decreased to a certain extent. The annealing texture may be stated as a strong (001)[100] texture with a weak $(124)[53\bar{3}]$ texture. For specimens FA4 and FA5, the secondary intensity of the deformation textures was further diminished, and a single texture of (001)[100] was approached. The pole figures were practically the same as reported by the previous investigators.[7,11]

Several micrographs have been prepared along the rolling plane of specimens FA3, FA4 and FA5 (Fig 9). The specimens were polished and deeply etched with a potassium bichromate solution. The white matrix with two sets of twin bands at 45° to the rolling direction indicates the grains to be in cubical alignment. It can be seen that there is a certain amount of dark grains other than cubic ones still existing in specimen FA3, whereas for specimens FA4 and FA5, the cubic texture is practically 100 pct.

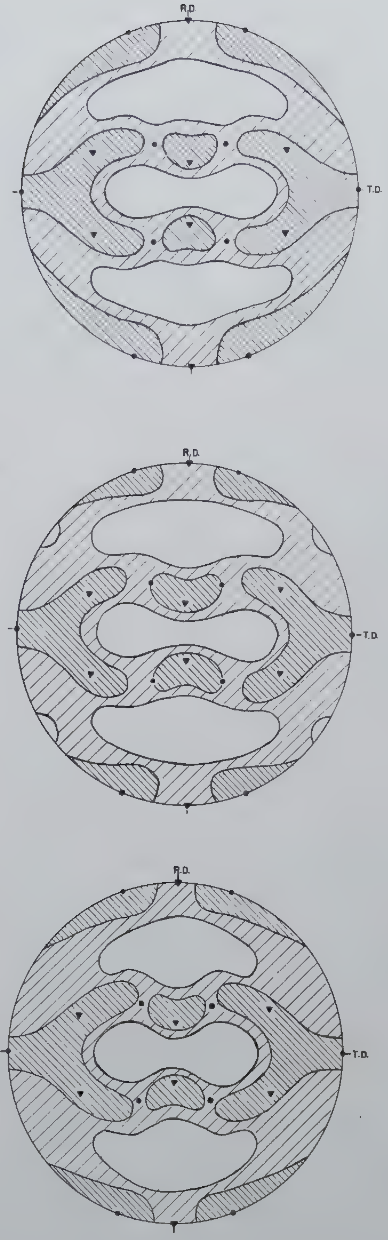

FIG 6—(111) pole figures of cold rolled copper strips.

a. FA1—Phosphorized (0.013 pct P) 89.0 pct Red. *b.* FA3—OFHC 88.6 pct Red. *c.* FA5—fire-refined 87.0 pct Red. Ideal orientations indicated as follows: ● $(110)[\bar{1}12]$, ▼ $(112)[11\bar{1}]$. *a.* (top) *b.* (center) *c.* (bottom).

The effect of phosphorus on the electrical conductivity and softening temperature of copper is well known. The work of Hanson, Archbutt and Ford[18] is typical. They found that the

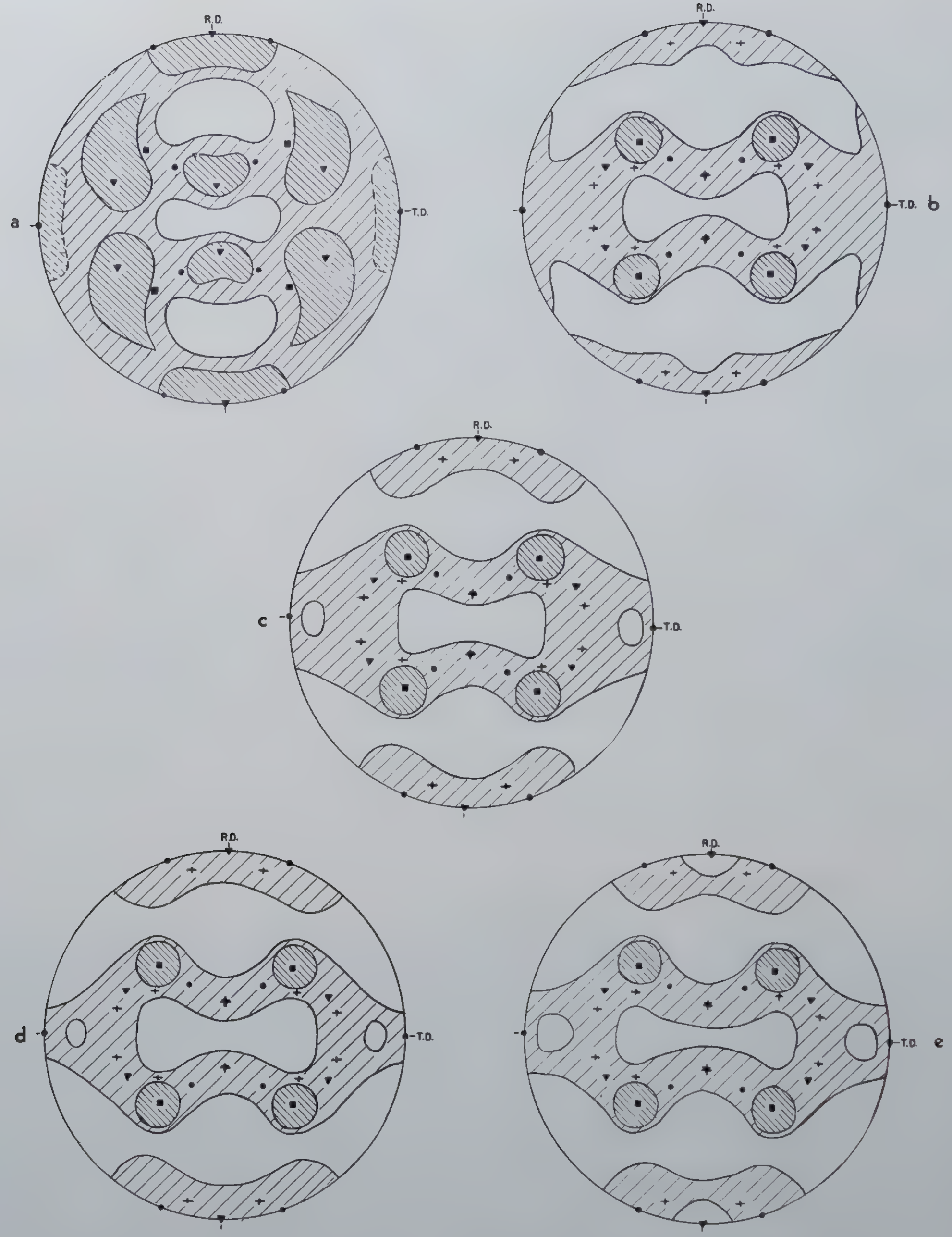

FIG 7—(111) pole figures for cold-rolled copper strips annealed at 900°F for one hour.
a. FA1—phosphorized (0.013 pct P), b. FA2—phosphorized (0.007 pct P), c. FA3—OFHC, d. FA4—electrolytic, e. FA5—fire-refined. Ideal orientations indicated as follows: ■ (100)[001], ● (110)[$\bar{1}$12] ▼ (112)[11$\bar{1}$], + (124)[53$\bar{3}$].

addition of phosphorus yielded a marked increase of softening temperature and a marked decrease of electrical conductivity. Recently, Smart and Smith,[19] stated that phosphorus when present in copper may be either in solid solution or in the oxidized condition. However, only the presence of phosphorus in solution has an important effect on the softening temperature and electrical conductivity. Thus, by comparing the conductivity measurement of specimens FA1, FA2 and FA3 with the results obtained by interpolating from the curves given by Smart and Smith,[19] the following table is obtained.

Table 3 . . . The Effect of Phosphorus on Electrical Conductivity and Softening Temperature of Copper

	Phosphorus Content pct	Electrical Conductivity pct IACS	Softening Temp. °C
Oxygen-free Alloys	0.013	93.0	305
	0.007	97.2	292
	0.0002	102.3	182
Oxygen-bearing Alloys	0.013	102.1	140
	0.007	102.2	140
	0.0002	102.3	140
FA1 (Phosphorized)	0.013	94.6	295
FA2 (Phosphorized)	0.007	101.4	170
FA3 (OFHC)	<0.0003	101.3	200

The electrical conductivity of specimens FA1, FA2 and FA3 was measured on samples in a condition comparable to that used by Smart and Smith.[19] However, the softening temperatures of the present specimens were determined from the hardness curves in Fig 2, where the greatest change of slope of these curves occurred. Therefore, the value listed in Table 3 could only be used for a qualitative comparison among each group.

From Table 3, it may be stated that the largest part of the phosphorus in specimen FA2 existed in the oxidized form, whereas that in specimen FA1 was most likely in solid solution with copper. The higher recrystallization temperature of FA1 and the lower value of FA2 also bear out this fact. It has been pointed out that recrystallization textures are subject to considerable variation because of alloying elements in solution. Furthermore, elements which conferred the greatest solution and strain-hardening on copper have shown the most complicated annealing texture.[11] It appears, therefore, certain complications will be introduced, in that the amount of phosphorus obtained by chemical analysis may not be used as a guide to specify the influence on the textures. The development of annealed texture for specimen FA1 may therefore be considered as following a different mechanism than that of specimen FA2 because of the different condition of phosphorus in each. In the case of H.C. copper, it was found that a well developed deformation texture—up to 80 to 95 pct reduction—was required before recrystallization would produce the cubic texture. For reductions of 50 to 80 pct, the texture existing in the annealed condition resembled that in the rolling condition.[6] Referring to the rolling texture of specimen FA1, the greater spread of the major intensity of (111) distribution can be best ascribed to the presence of the minor texture (110)[001], which was found to be one of the intermediate orientations in cold-rolled copper.[3,20] Thus it may be suggested that the absence of cubic texture in specimen FA1, probably due to the strain-hardening effect of the phosphorus in solid-solution, is analogous to that of H.C. copper deformed below 80 pct reduction. The random orientation at lower temperature and the development of a mixed (112)[11$\bar{1}$] and (110)[001] texture at 1600°F may also be attributed to the interference of phosphorus with the recrystallization mechanism.

The recrystallization texture of specimen FA2 annealed at lower temperature exhibited the same characteristics as specimens FA3, FA4 and FA5, that is, a strong cubic texture superimposed on a mixed deformation texture. However, when the annealing temperature was sufficiently high, above 1400°F, the cubic texture diminished in intensity and there was a great increase in grain size. The development of the large grains has been reported by Dahl and Pawlek[10] for electrolytic copper of 100 pct cubic texture annealed at high temperatures. They stated that the texture could be described as (120)[100]. The large grains have also been observed in annealed copper by Cook and Richards[21] and Baldwin[8] to possess a texture of (110)[1$\bar{1}$2]. It was also found by Baldwin[8] that the orientation of the huge grains growing out of a 100 pct cubic texture for lake and electrolytic copper can be best described as: (113) in the rolling plane and between [110], [301] and [2$\bar{1}$1] in the rolling direction. It might be suggested that the cubic orientation would be unfavorable under the process of grain growth, or in other words, it is less stable in large grains than other orientations described above. It appears, therefore, that the change of annealing texture as well as earing position in specimen FA2 at 1600°F could be considered to be a result of the absorption of grains of the cubic orientation during the grain growth leaving the other orientations predominant.

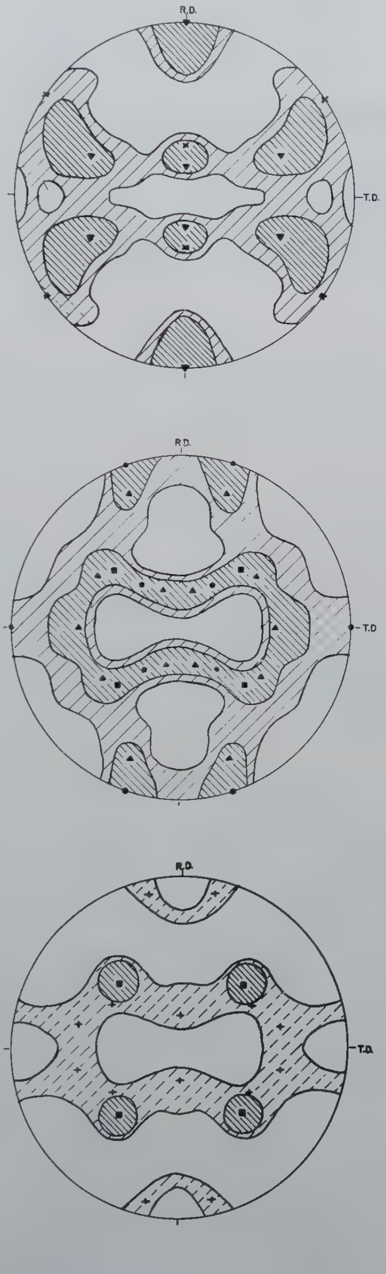

FIG 8—(111) Pole figures for cold-rolled copper strips annealed at 1600°F, for one hour.

a. FA1—Phosphorized (0.013 pct P), *b.* FA2—Phosphorized (0.007 pct P), *c.* FA3—OFHC. Ideal orientations indicated as follows: ● (110)[$\bar{1}$12], ▼ (112)[11$\bar{1}$], × (110)[001], ■ (100)[001], ▲ (113)[$\bar{2}\bar{1}$1], +(124)[53$\bar{3}$]. *a* (top) *b* (center) *c* (bottom)

Summary

1. The cold-rolled texture of different types of copper strip was found to be less sensitive to the presence of phosphorus or other impurities than the recrystallization one. The ideal orientations of rolling texture may be described as the usual type, (110)[$\bar{1}$12] + (112)[11$\bar{1}$], but greater spread of the first intensity of (111) poles in phosphorized copper FA1, (0.013 pct P), may be considered as due to the presence of the minor texture (110)[001].

2. The recrystallization textures of phosphorized copper containing 0.013 pct P exhibited a rather random pattern for annealing at lower temperature, while at high temperature there was produced a texture of mixed orientations (112)[11$\bar{1}$] and (110)[001]. There was no appreciable change of earing position throughout the whole range of anneal.

3. The texture of phosphorized copper FA2 (0.007 pct P), oxygen-free high-conductivity copper FA3, electrolytic copper FA4 and fire-refined copper FA5, annealed at 900°F was found to be a strong (001)[100] texture superimposed on the retained deformation textures (124)[53$\bar{3}$], (110)[$\bar{1}$12] and (112)[11$\bar{1}$]. These minor orientations usually diminished in their intensities with an increase of final annealing temperature, while, in turn, a single cubic texture was approached in specimens of oxygen-free high-conductivity copper FA3, electrolytic copper FA4 and fire-refined copper FA5. For phosphorized copper containing 0.007 pct P, FA2, annealed at 1600°F, a texture of a mixture of orientations (113)[$\bar{2}\bar{1}$1], (110)[$\bar{1}$12] and (100)[001] was found, while the earing position in drawn cups changed from a pure copper type at 0° and 90° to 45° to the rolling direction.

4. In studying the data of electrical conductivity and softening tempera-

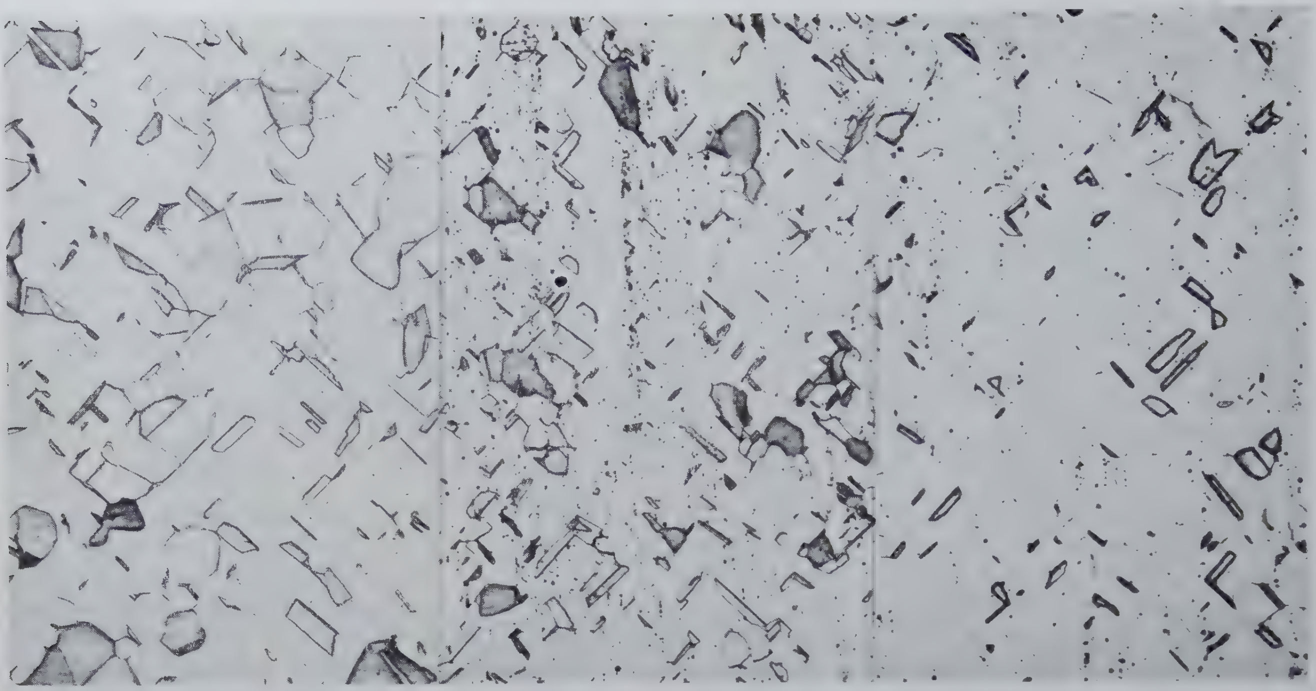

FIG 9—Microstructures of three types of copper strips annealed one hour at 1600°F.
a. FA3—OFHC, *b.* FA4—Electrolytic, *c.* FA5—fire-refined. Potassium Bichromate solution etch. × 75. *a* (left) *b* (center) *c* (right)

tures of two types of phosphorized copper, it was suggested that the presence of phosphorus in coppers FA1 (0.013 pct P) and FA2 (0.007 pct P) would be in different conditions. Most of the phosphorus in FA1 may be considered as existing in solid solution with copper; thus the great influences on electrical conductivity, recrystallization temperature as well as textures and earing behavior would result. In specimen FA2, it appeared that most of the phosphorus probably existed in the oxidized form, which had less effect on the texture and earing behavior. However, the change of texture and position of ears at high temperature may be rationalized as the same function of development of various textures in the huge grains where the cubically aligned grains may be less stable than the others.

5. In regard to the earing behavior of these copper strips, it may be stated that the type and degree of preferred orientation are the most significant factors controlling the height and position of ears. An increase in grain size will usually have a tendency toward a preferred orientation, which in turn produces higher ears. The absence of ears in drawn cups may or may not indicate the absence of preferred orientation, but may be due to the presence of orientations which counteract one another with respect to the earing behavior.

Acknowledgment

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Use of Electrical Resistance Measurements to Determine the Solidus of the Lead-tin System

RALPH HULTGREN,* Member AIME, and STANLEY A. LEVER†

The solidus is usually the least satisfactorily determined portion of a phase diagram. Cooling curves, which succeed well with the liquidus, show the solidus inaccurately or not at all because of segregation which occurs during freezing. Heating curves of carefully homogenized alloys might be expected to indicate accurately the solidus, but they are seldom used.

Dynamic methods involving heating or cooling are never completely satisfactory because of uncertainty as to whether equilibrium is attained. A static method in which the specimen may be allowed hours, days, or even weeks to attain equilibrium is to be preferred. In a static method a solid solution, for example, is first made thoroughly homogeneous, then heated to successively higher temperatures. After sufficient time at each temperature to assure equilibrium, some property is measured which should alter strikingly when melting begins. Microscopic examination can be used to detect the beginning of melting, but the method is tedious since the specimen must be quenched, sectioned, polished, and etched before each examination.

Of all the physical properties which change on melting, electrical resistance is probably the most satisfactory to measure. The measurement may be made while the specimen is at temperature without damage to the specimen. It may be repeated indefinitely to ascertain when equilibrium has been achieved. Measurements may be made on a single specimen over the whole range of temperature. Most metals approximately double their resistance on melting. Since an accuracy of a few tenths of a percent is easy to achieve, the method is highly sensitive to the beginning of melting.

In spite of these advantages, which have been perceived for a long time,[1,2] a reasonable search of the literature has failed to reveal a single case in which the method has been satisfactorily applied in practice to the determination of solidus temperatures. The use of electrical resistance measurements appears to have been confined in practice to changes in the solid state.

In the work described in the following pages we have applied the electrical resistance method to the solidus of the lead-tin system. We have found the method to be convenient, reproducible, and highly sensitive. We chose the lead-tin system because it leads to few technical difficulties. Furthermore, a number of determinations of solidus have been made in this system by various methods and results could be checked against them. However, all published results are not in good agreement with one another, so this work should help in determining the solidus more precisely.

The Lead-tin Diagram

Because of its commercial importance, there have been numerous investigations of the lead-tin diagram. The results of the most recent work on the solidus are indicated in Fig 7, as well as the results of the present work. The works of Honda and Abe[3] and of Stockdale[4] agree fairly well with each other and with the present work. Jeffery's[5] data indicate the solidus to be about 50°C lower.

Honda and Abe[3] used differential thermal analysis on both heating and cooling cycles. Stockdale[4] used the microscopic method and also differential heating curves. Stockdale's results were about 4° higher than those of Honda and Abe at low tin contents and lower at higher tin contents. These results also agree with those of Rosenhain and Tucker.[6]

Jeffery[5] used electrical resistance measurements of the alloy as it was being heated or cooled. Apparently he did not attain equilibrium as his results are about 40°C lower than those of Stockdale[4] or Honda and Abe.[3]

MATERIALS AND METHODS

The lead and tin used were of high purity. They were supplied by the American Smelting and Refining Co., who gave the following analyses:

Lead: silver, 0.0016 oz per ton; copper, 0.0008 pct; cadmium, 0.0007 pct; zinc, 0.0002 pct; arsenic, 0.0003 pct; antimony, 0.0002 pct; bismuth, 0.0005 pct; tin, 0.0001 pct; iron, 0.0020 pct; lead (by difference), 99.995 pct.

Tin: antimony, 0.037 pct; arsenic, 0.020 pct; bismuth, 0.004 pct; cadmium, trace; copper, 0.025 pct; iron, 0.004 pct; lead, 0.020 pct; nickel and cobalt, 0.005 pct; silver, 0.0005 pct; sulphur, 0.005 pct; tin (by difference), 99.88 pct.

One hundred grams of metal with the desired proportions of lead and tin was weighed out to the nearest one-tenth of a milligram. The mixture was placed in a silica crucible, covered with charcoal, and melted in a reducing atmosphere in a gas-fired furnace. The alloy was well stirred. Chemical analysis of two of the alloys checked closely with the weighed portions. The compositions of the remainder of the alloys were taken directly from the weighings, without chemical analysis.

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TP 2500 E, January 1949. Discussion of this paper (2 copies) may be sent to *Transactions* AIME before April 15, 1949. Manuscript received September 10, 1948.

Most of the material presented in this paper was abstracted from a thesis submitted by Stanley A. Lever in partial fulfillment of the requirements for the degree Master of Science in Engineering, University of California.

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† Univ. of California, Berkeley.

[1] References are at the end of the paper.

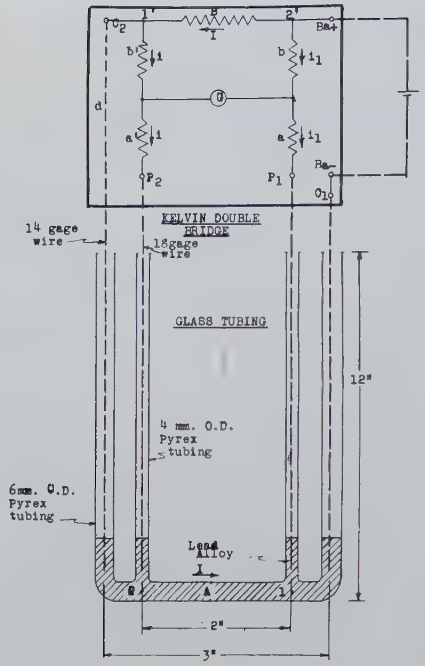

FIG 1—Pyrex U-tube and electrical connections to Kelvin double bridge.

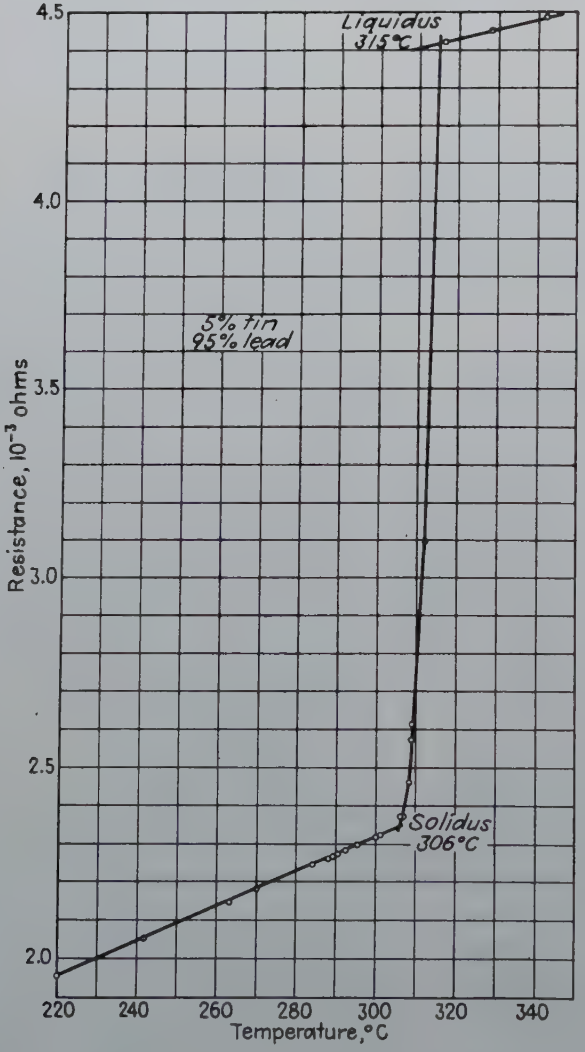

FIG 2—Electrical resistance vs. temperature, 5 pct tin alloy.

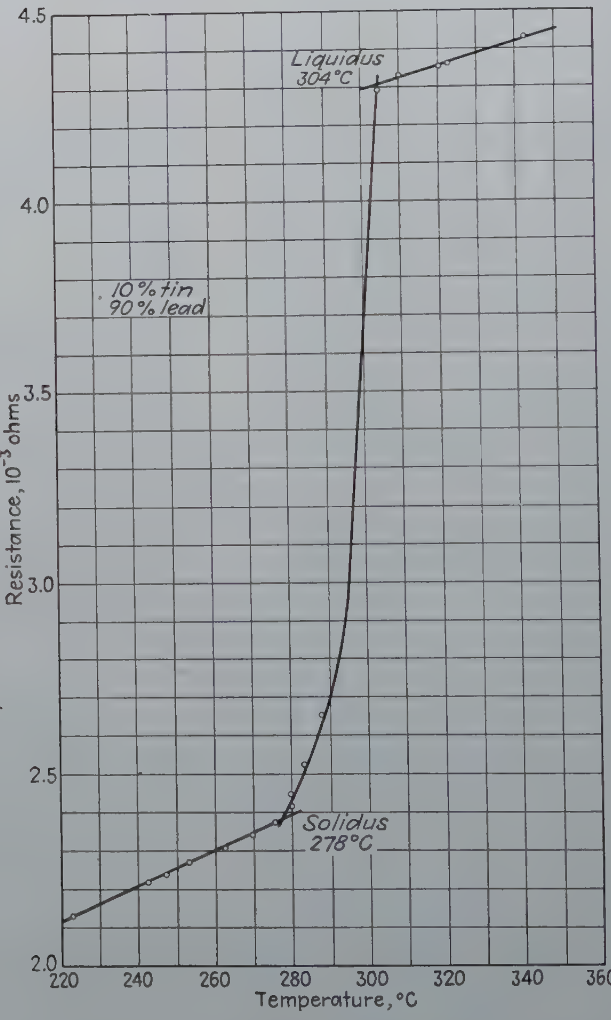

FIG 3—Electrical resistance vs. temperature, 10 pct tin alloy.

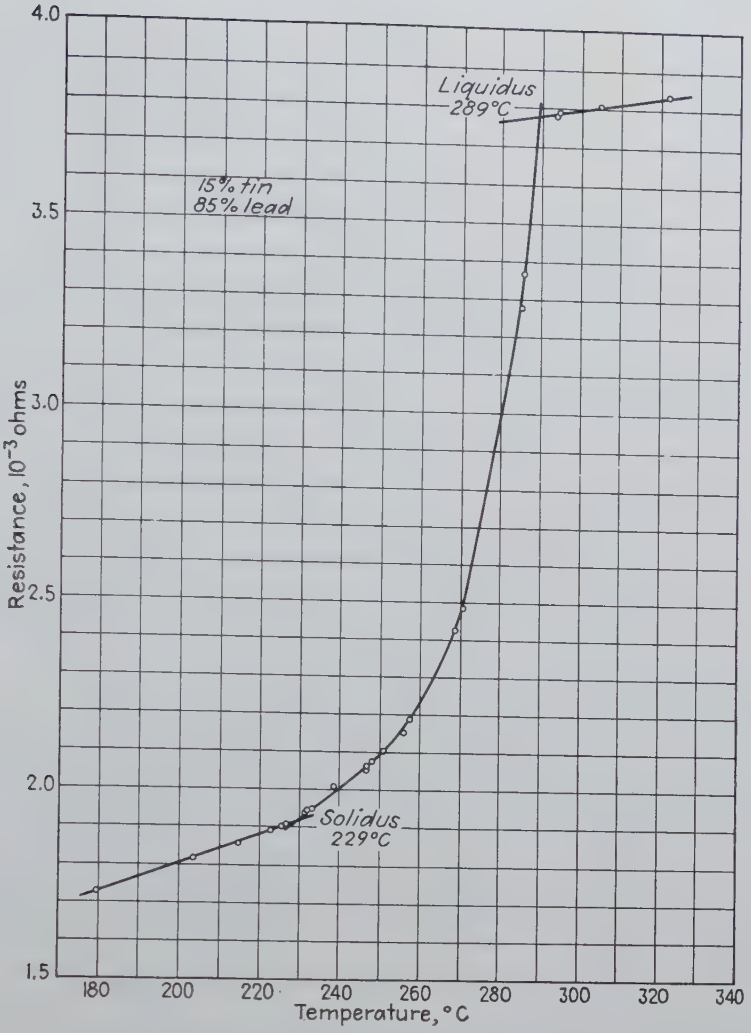

FIG 4—Electrical resistance vs. temperature, 15 pct tin alloy.

The pyrex glass tubing shown in Fig 1 was heated in a Lindberg cyclone furnace and held at a temperature of 400°C. A gas mixture consisting of 98 pct nitrogen and 2 pct hydrogen was passed through it for about one-half hour. The well stirred molten alloy was then poured into the tubing and allowed to remain for about one-half hour while electrical connections were being inserted.

The electric lead wires had been stripped of insulation, cleaned with nitric acid and finally washed with alcohol and dried. Stranded 14-ga copper wires were introduced into the outer arms of the tube, and stranded 18-ga copper wire into the inner arms. Fine (30 ga) iron-constantan thermocouple wires insulated with braided glass were introduced so that the hot junction was at point 1. The tube was then removed from the furnace and cooled rapidly in a stream of cool air in order to minimize segregation on freezing. Before measurements were taken, the alloy in the tube was given a homogenizing anneal of about two days at a temperature about 50°C below Stockdale's value of the solidus.

For the measurements of electrical resistance the tube was heated in a metal bath composed of lead, tin, and bismuth and having a melting point of about 170°C. The temperature of the bath was held constant to ±1°C.

Resistance measurements were made with a Leeds and Northrup Kelvin Double Bridge Ohmmeter. This bridge is more suitable than a Wheatstone bridge for low values of resistance, since the effect of contact resistance is very small. A diagram of electrical connections is shown in Fig 1. External leads are shown as dotted lines. The external electrical leads were approximately 2 ft long. The leads to the connections C_1 and C_2 each consisted of two 14-ga stranded copper wires in parallel, those to P_1 and P_2 of two 18-ga stranded copper wires in parallel. The readings of resistance were estimated to be accurate to about 0.000005 ohms, which is of the order of 0.2 pct.

In making the measurements it was necessary to pass a current of about 7 amp through the metal for a period of less than 15 sec. It can be shown that this is capable of raising the temperature of the alloy less than 2°C. Measurements with the thermocouple imbedded in the alloy indicated the actual temperature rise during a measurement was less than 0.2°C.

Temperature measurements of the alloy were made on a precision potentiometer using the very fine (30 ga) iron-constantan thermocouple mentioned above. Readings are estimated to be accurate to about 0.5°C.

During the homogenizing anneal, electrical resistance measurements were taken from time to time. It was usually observed that the values obtained changed slowly for about two days,

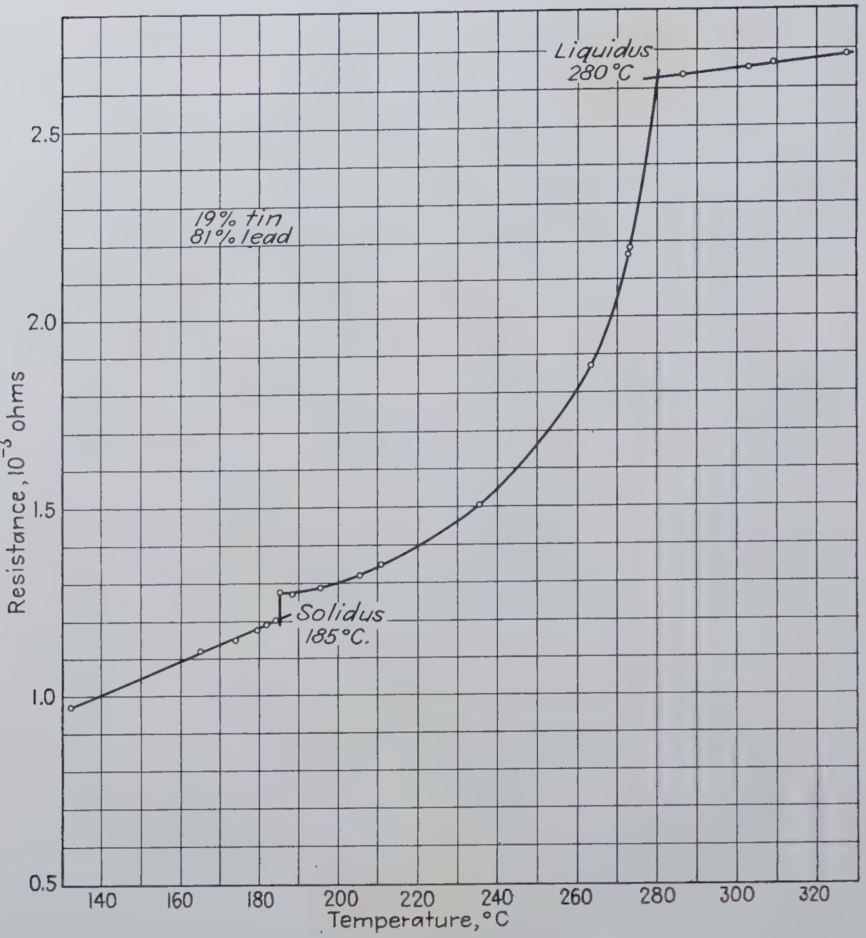

FIG 5—Electrical resistance vs. temperature, 19 pct tin alloy.

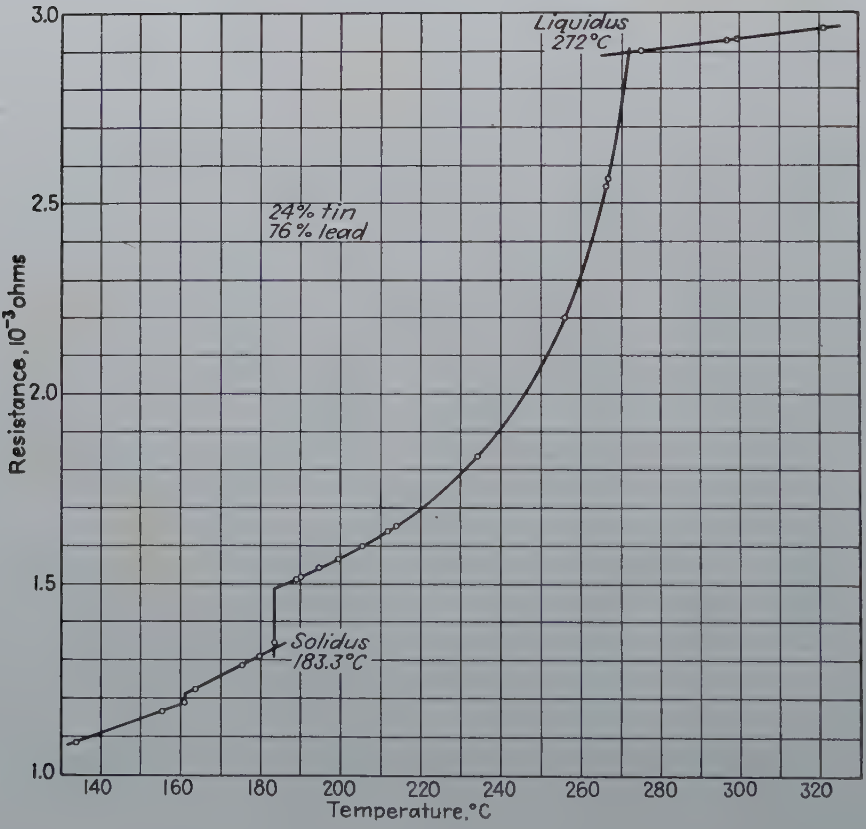

FIG 6—Electrical resistance vs. temperature, 24 pct tin alloy.

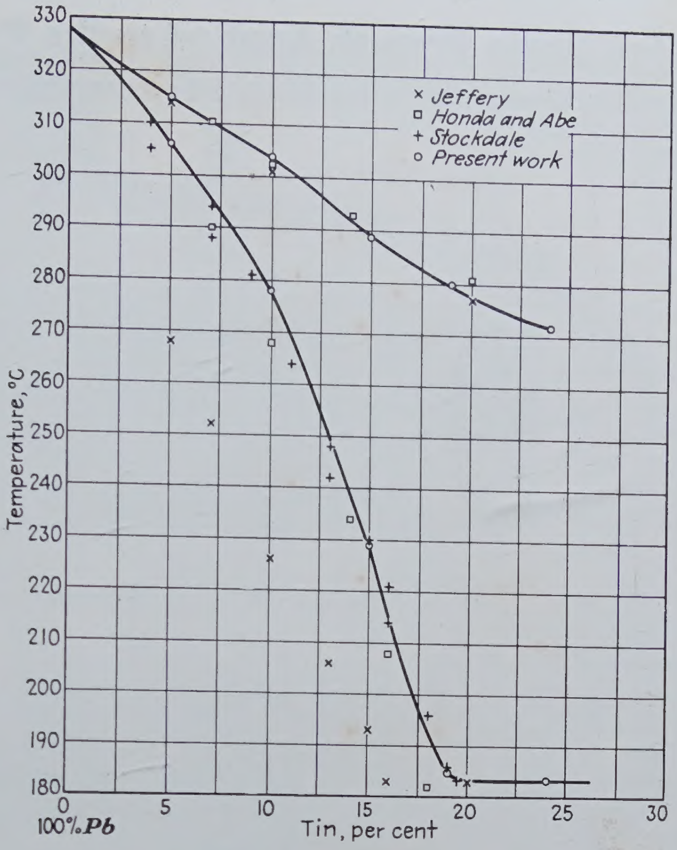

FIG 7—Solidus and liquidus of lead-tin system.

then settled to a constant value. This was taken to indicate that the alloy was homogeneous and the resistance was recorded.

The temperature of the bath was then raised a few degrees and held there until the resistance readings again became constant. Usually five to six hours was allowed for this, although in many cases the alloy remained at temperature overnight. When the resistance did not change for one hour, it was assumed that equilibrium was attained. This process was continued through the solidus and liquidus of the alloy. Temperature intervals in critical regions amounted to only two or three degrees.

Results and Conclusions

The resistance vs. temperature curves obtained are shown in Fig 2–6. As can be seen, these curves are accurate straight lines for the alloy in the solid state. As the alloy begins to melt at the solidus, however, there is a sharp increase in slope of the curve. The experimental points follow the curves accurately, so that the solidus is determined precisely in each case. There is a similar sharp change in slope at the liquidus.

In the alloys containing 19 and 24 pct tin (Fig 5 and 6), melting begins at 183°C with a small discontinuity in the curve. This is due to the melting of a small amount of the eutectic.

In the alloy containing 24 pct tin, there is also a small but sharp discontinuity at 161°C. We attribute this to a change in the tin-rich phase, which is present in appreciable amount only in this alloy. Other observers[7] have noted discontinuities in volume and electrical resistance in tin at this temperature although this result is disputed by some. Mason and Pellissier[7] report that the high temperature X ray camera shows there is no change in phase of tin at elevated temperatures. To add to the confusion, observers have reported discontinuities at a number of other temperatures. We are unable to account for our result.

The solidus and liquidus points determined in this investigation are plotted in Fig 7, along with the results of other investigators. The liquidus determinations of all workers agree excellently. Except for the work of Jeffery,[5] the solidus points fall rather closely together. However, our results are somewhat higher than those of Honda and Abe[3] at all compositions, and higher than those of Stockdale[4] at low tin contents. The fact that residual segregation would cause results to be too low rather than too high indicates that our results are to be preferred.

We believe this work has shown that electrical resistance measurement is a convenient method of determining the solidus (and the liquidus) curve with high precision.

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Controlled Grain Growth Applied to the Problem of Grain Boundary Energy Measurements

C. G. DUNN,* Member AIME

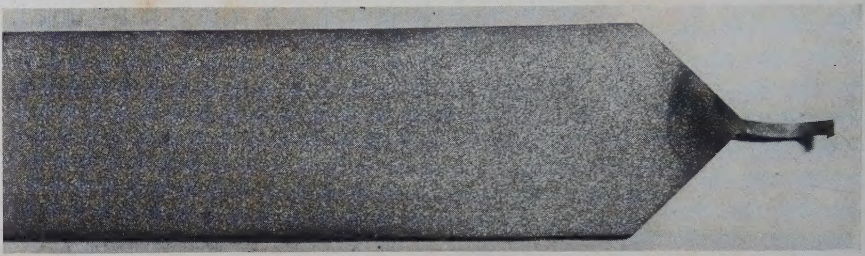

FIG 1—Photograph showing fine grained specimen with reoriented seed crystal in the form of small flag on end of the narrow twisted part of the specimen. Natural size.

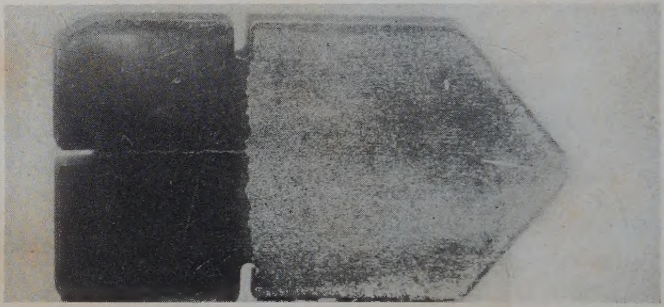

FIG 2—Photograph showing specimen composed of three grains each having a {110} plane in the plane of the specimen. Sample ready to be annealed. × 2.

THE measurement of interfacial tensions or grain boundary energies in metals is an important metallurgical problem, especially since it bears on growth and nucleation processes. Statistical methods of measuring equilibrium grain boundary angles, which relate interfacial tensions, have been used by some investigators[1,2] but more direct methods would be preferred.

A direct way, based on a simple extension of a successful method of growing single crystals of silicon ferrite to predetermined orientations in flat specimens,[3] is to produce three-grain specimens in such a way that the equilibrium common grain boundary will be perpendicular to the surface of the specimen. The angles to be measured then appear as the grain boundary angles in the surface of the specimen.

The method of producing a single crystal specimen with a predetermined orientation is basically the same as that employed by Yoshida and Fujiwara[4] in their work on aluminum wires. The specimen, prior to any single crystal transformation, must have a matrix which will support the growth of a crystal of the desired orientation. Growth may occur through exaggerated grain growth or, if the matrix is strained a critical amount, by normal recrystallization. In either case the matrix must have stability at the temperature used to effect the transformation, this stability appearing as a long induction period for exaggerated grain growth or for the formation of recrystallization nuclei. Additional control is gained by using a high temperature gradient through which the specimen is moved at a suitable rate. To obtain the desired orientation, the specimen is fed a short way into the furnace producing one or more crystals in the hot end. After the specimen is removed from the furnace, the orientation of a crystal is determined, so that this crystal may be reoriented by properly deforming a narrow piece of the matrix between the end crystal and the rest of the specimen. This part of the specimen in the case of silicon ferrite is preferably held at red heat during the reorienting process. Fig 1 shows a specimen which is ready to be transformed into a single crystal through growth of a reoriented "seed" crystal.

When the method just described is applied to the production of a three-grain specimen two crystals are grown first side by side in one end, the specimen is then reversed and the third grain grown from the opposite end. A suitable group of grains each of different orientation is one where all three grains have the same crystallographic plane in the plane of the specimen.†

Fig 2 shows a photograph of a three-grain group prepared as described. The notches are introduced in the open ends of the grain boundaries to anchor them during the final annealing operations which ultimately should bring the grain boundaries to the lowest energy configuration.

Two-grain groups with different crystallographic planes in the plane of the specimen can be similarly prepared and treated. If the two grains have different surface (gas to metal) energies per unit area, the equilibrium condition leads to a curved grain boundary.*

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† F. Lionetti and the writer are investigating a series of groups all crystals of which have a {110} plane in the plane of the specimen. Results of this investigation, when complete, will be published.

* This feature of the problem was pointed out by J. C. Fisher.

Technical Note No. 9. Manuscript received September 27, 1948.

* Research Physicist, General Electric Co., Pittsfield, Mass.

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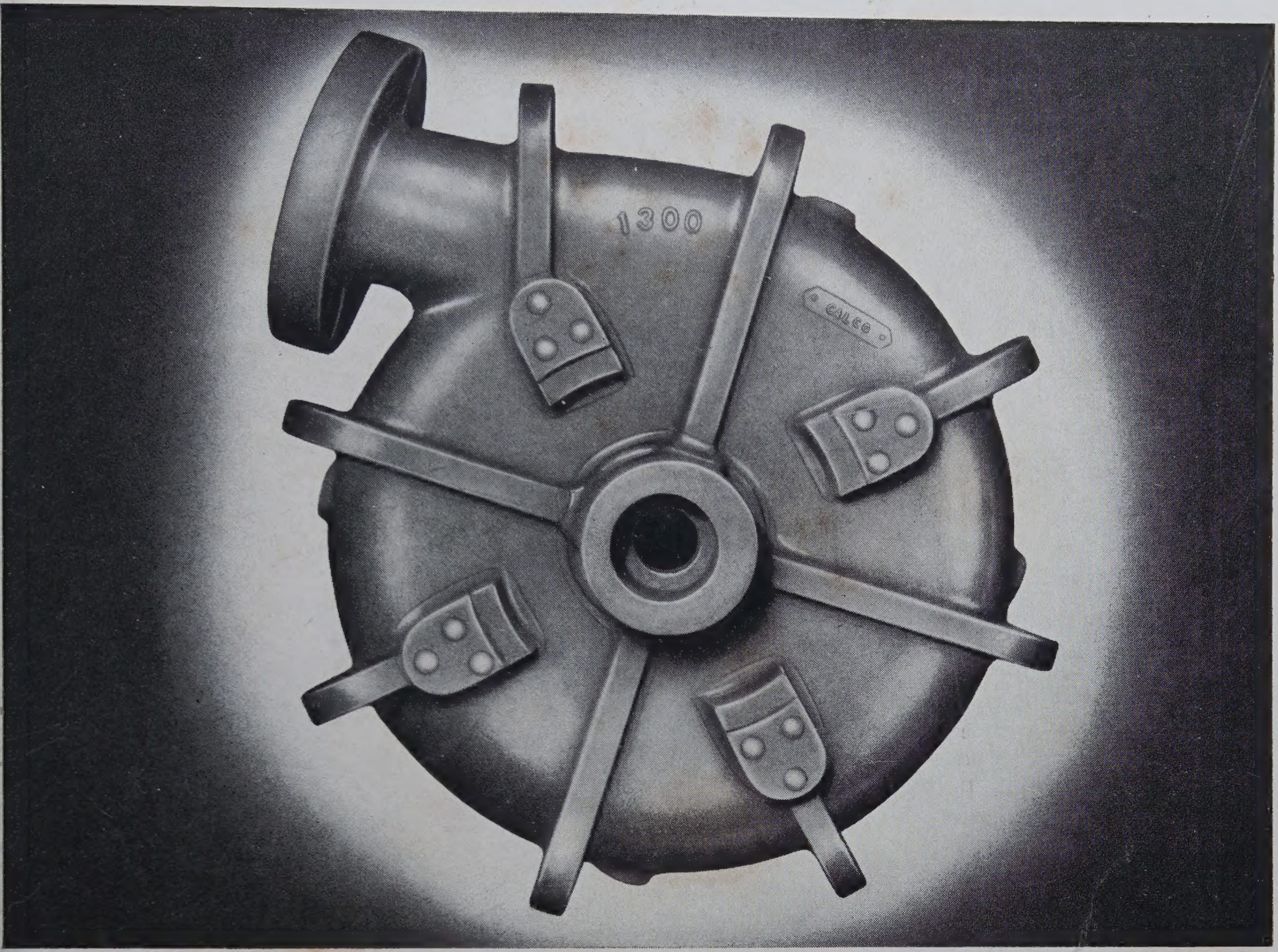

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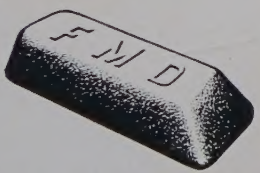

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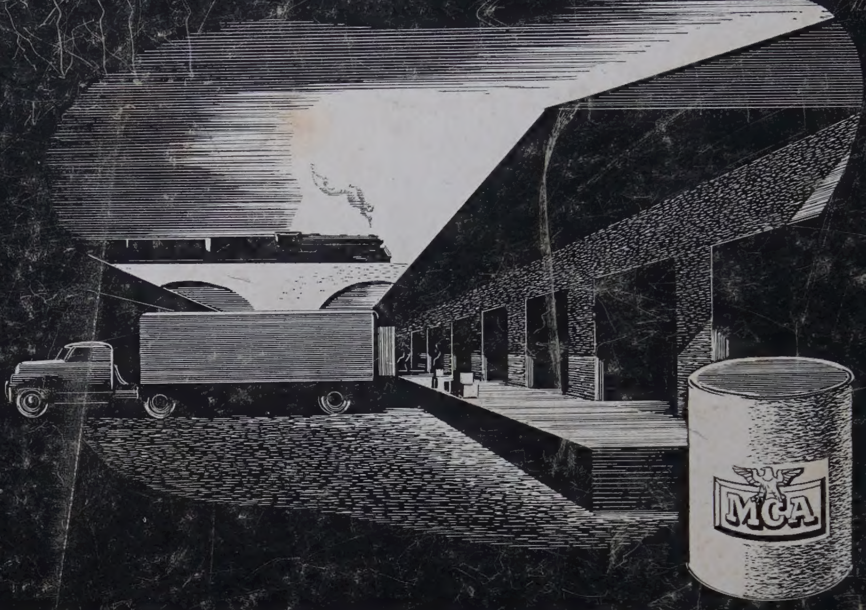

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